Mines and Minerals Branch Report of Activities 1982

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MINES AND MINERALS BRANCH
REPORT OF ACTIVITIES

1982

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COAL EXPLORATION IN THE SYDNEY COALFIELD IN 1982

D.J. MacNeil

TRACY SEAM

The Tracy seam was investigated for near surface coal on that portion of the seam lying between MacDonald Lake and Broughton (Fig. 1), a distance of 3.5 km.

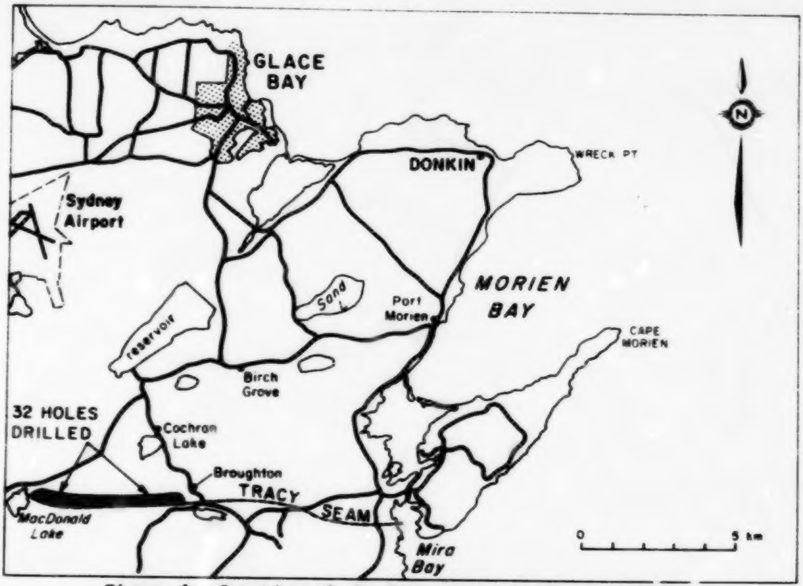
GLACE BAY
DONKIN
WRECK PT
N
Sydney Airport
MORIEN BAY
Sand L.
Port Morien
reservoir
CAPE MORIEN
Birch Grove
32 HOLES DRILLED
Cochran Lake
Broughton
TRACY SEAM
MacDonald Lake
0
5 km
Mira Bay

Figure 1. Location of the Tracy seam, Sydney coalfield.

The seam was intersected by 25 holes during the 1982 field season with 812 m being drilled at an average of 32 m per hole. The program was designed to complement the preliminary drilling program carried out in 1978 which consisted of seven holes on the western end of the Tracy seam.

The results of drilling have shown that approximately 1.2 million t are available for surface mining at a strip ratio of 12.5:1. The seam averages 1.2 m in thickness, exhibits a 9° dip to the north and has an ash content of 12 per cent and a sulphur content greater than 6 per cent. The calorific value is 29.8 Mj/kg (12 800 Btu/lb.)

West of MacDonald Lake, the Tracy seam deteriorates both in thickness and quality. To the east open-pit mineable reserves are limited by underground workings at Broughton and by the appreciable thicknesses of glacial overburden (20-30 m) encountered overlying the Tracy crop.

GARDINER SEAM

A near surface coal resource was outlined east of the Sydney airport in 1981 (Fig. 2). In this area a 3.2 km strike length was drilled and 1.2 million t of coal were outlined on the Gardiner seam using 4.5° dip at a 12.5:1 strip ratio. The seam averages 95 cm in thickness with 11.6 per cent ash and 3.3 per cent sulphur. An "as received" calorific value is 30.6 Mj/kg (13 170 Btu/lb.). The seam deteriorates in quality eastward.

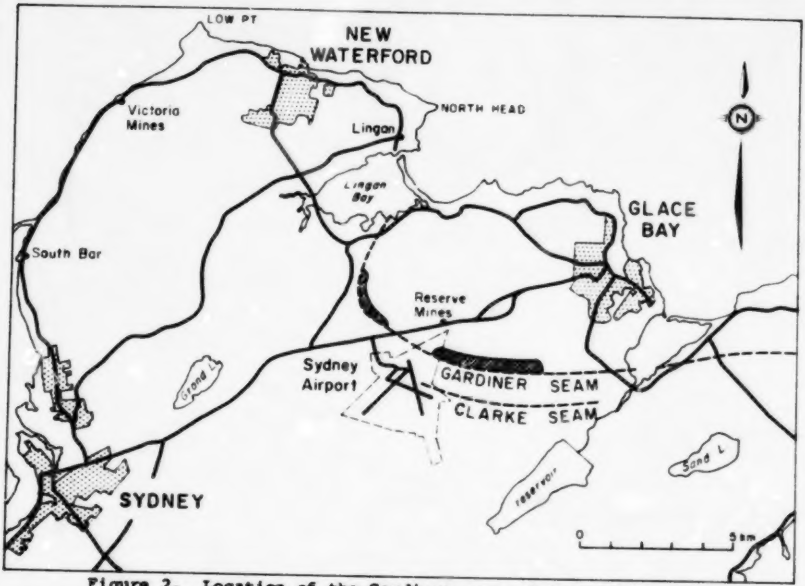
LOW PT
NEW WATERFORD
NORTH HEAD
Victoria Mines
Lingan
Lingan Bay
GLACE BAY
N
South Bar
Reserve Mines
Sydney Airport
GARDINER SEAM
CLARKE SEAM
Grand L
Sand L
reservoir
SYDNEY
0
5 km

Figure 2. Location of the Gardiner seam, Sydney coalfield.

In addition to the Gardiner a second seam, the O'Dell, overlies the Gardiner seam by 6 m to 9 m.

The O'Dell seam averages 1.5 m in thickness, but is characterized by its variability with abundant shaly partings and mudstone splits. It deteriorates westward. Sulphur ranges from 6 to 10 per cent and ash is generally greater than 20 per cent. Since extraction of this seam is concomitant with that of the Gardiner, the possibility of beneficiation of the O'Dell should not be overlooked.

During the 1982 field season, three fill-in holes were drilled on the O'Dell and Gardiner seams for a total of 104 m.

MISCELLANEOUS

Two holes were drilled in 1982 to test the Upper Lorway or Clarke seam which crops approximately 1 km south (structurally below) of the Gardiner seam (Fig. 2). Only a coaly shale horizon was intersected in a mixed red and grey shale-sandstone sequence. No recoverable coal is considered to be in this area.

STUDIES IN THE SPRINGHILL COALFIELD

J. H. Calder and R. Naylor

During the past year investigations in the Springhill coalfield have fallen into three catagories: 1) diamond-drilling of selected targets; 2) mapping within the Novaco open-pit mine; and 3) preparation of an overview paper on the Springhill coalfield. 1982 has been significant because of the return to mining in the coalfield after 12 years of inactivity. A brief summary of these investigations follows.

EXPLORATION ACTIVITIES

The five target areas investigated by diamond-drilling are:

1) the Rodney seam on the anticlinal axis (both at depth and near surface),

2) the No. 3 seam (upper and lower leaves) north of workings in the No. 3 mine,

3) the Nos. 6 and 7 seams, north of workings in the Nos. 6 and 7 mines,

4) coal-bearing strata beneath the No. 6 seam,

5) coal seams (Nos. 6 and 7) outcropping east of Springhill at Lloyd's slope brook.

On the Rodney seam, four holes (SH61-SH64) with a total depth of 1152 m were successfully completed. These drillholes were aimed at better defining and expanding measured resources downdip from areas investigated during the past two years. Five drillholes (SH65-SH69) totalling 331 m were drilled in and around the Novaco open-pit mine on the Rodney seam.

Drill crews were employed at the No. 3 upper and lower leaves, north of workings on those leaves. Drillholes SH70-SH72, totalling 316 m, delineated the depositional margin of the No. 3 seam in this area, effectively eliminating this site as a potential open-pit resource. Drilling proceeded on the Nos. 6 and 7 seams, also north of workings. Drillholes SH73 and SH75, totalling 126 m, intersected favourable coal, however, the steep dip in this area has necessitated closer scrutiny of its mineability. Therefore, drilling was temporarily suspended at this location in favour of exploration on the little-known coal seams at Lloyd's slope. At Lloyd's slope two holes (SH76 and SH77) were completed intersecting seams deposited which have been tentatively correlated with the No. 7 lower and No. 6 seams. The quality of coal reflects a marginal environment of coal formation, therefore no further drilling is envisaged at this location in the near future.

One 75 m drillhole (SH79) was also completed on the potential open-pit site delineated by Wimpey (Ward, 1979) in the Rodney area, before the drill was moved to the crown pillar of the No. 3 seam on the north limb of the Springhill Anticline. Drilling related to assessment of the viability of open-pit mining in this area is presently continuing.

A second drill came on site in September and completed one 288 m hole (SH74) in strata beneath the No. 6 seam at the No. 6 mine. It was then engaged in the drilling of a 395 m hole in Leamington in an attempt to correlate drillholes SH8 and SH9 with deep holes on the Rodney seam. Assessment of the year's drilling efforts will take place in the winter of 1983.

MAPPING WITHIN NOVACO OPEN-PIT MINE

Mapping was conducted from May through August 1982 in the Novaco open-pit mine of the Rodney seam (Fig. 1). A 1:500 structure map was completed after detailed mapping and considerable time spent in deciphering the chronological sequence of faulting within the structurally complex northern half of the open-pit, now mined. The sequence of faulting, is as follows:

Episode	Category	Trend
C	6) thrust fault	060° to 110
	5) bedding plane faults and	NA
	4) minor normal faults	040°
B	3) normal cross faults	110°
A	2) scissors fault and	020° to 040°
	1) major normal faults	010° to 038°

Figure 1. Novaco open-pit mine on Rodney seam; June 1982.

The sequence generally decreases in relative magnitude from Category 1 to Category 6. Intensity of faulting is expected to decrease somewhat downdip in the area of underground resources, away from the influence of the Black River diapir to the northeast. Of particular interest was the occurrence of bedding plane and intimately related minor thrust faulting. Norwest Resource Consultants (1981) alluded to the possibility of bedding plane faulting during investigations conducted in the previous year. In addition to structural studies, insight was gained into the nature of cyclic multi-bed sandstones and other strata comprising cyclic bed sequences within the coalfield because of excellent exposures.

OVERVIEW PAPER ON SPRINGHILL COALFIELD

An overview of the geology of the Springhill coalfield, intended as a summary paper to acquaint geologists and mining personnel with various aspects of the coalfield, is now in preparation. Topics discussed include:

a) regional stratigraphy,
b) structural geology,
c) stratigraphy and correlation of coal seams including changes in seam nomenclature,
d) coal petrography and environment of deposition including identification of the megaflora collected by various geologists,
e) a preliminary geological map of the Cumberland coal basin.

Publication is expected in 1983.

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Norwest Resource Consultants Ltd.,
1981: Geological evaluation of the Springhill project, v. 1-6; Report No. 8115/6, unpublished, Calgary, Alberta, 94 p.

Ward, B.
1979: Opencast coal potential at Springhill Nova Scotia; Nova Scotia Department of Mines and Energy, Paper 79-2, 40 p.

GEOLOGICAL EVALUATION OF THE MCKAY SEAMS,
THORBURN COAL DISTRICT,
PICTOU COUNTY, NOVA SCOTIA

R. Naylor and S. Chesal

SUMMARY

The McKay seams of the Thorburn coal district have been the target of two recent drill programs by the Nova Scotia Department of Mines and Energy. As a result of these programs, a potential open-pit site on the Upper and Lower McKay seams, representing a total resource of approximately 1 710 040 t, has been identified.

The raw coal quality of the reserve is predicted to be:

	Upper McKay	Lower McKay
Moisture (per cent)	2.92	2.57
Ash (per cent)	23.40	29.02
Sulphur (per cent)	1.53	3.30
Calorific Value (kJ/kg)	24.57	22.26
(Btu/lb)	10 542	9549
Seam Thickness (m)	1.26	1.20

At present, no major structural problems are anticipated which would pose a potential hindrance to mining. However, the proposed depositional envioronment of the McKay seams suggests that local abrupt changes in coal quality are possible.

The complete copy of the McKay seams report is on open file and includes the following information:

1. **Stratigraphic**

   - generalized lithologic logs matched to gamma and density logs (scale 1:250).

   - detailed lithologic logs (scale 1:50).

   - stratigraphic cross-sections of proposed mine area (scale 1:250 vertical, 1:1000 horizontal).

   - depositional model of McKay seams and its mining implications.

2. **Structural**

   - structural contour maps of McKay seams (1 m interval) over proposed mine area (scale 1:2000).

   - structural cross-sections of mine area (scale 1:1200).

3. Coal Quality and Tonnage

- Per cent ash and per cent sulphur isomaps of McKay seams contoured at 5 per cent for ash and 0.2 per cent for sulphur (scale 1:2000).
- Seam thickness isomaps McKay seams (scale 1:2000).
- Statistical study of association between amount of mudstones overlying the McKay seams and coal quality.
- Reserve calculations, surface reserve maps (scale 1:5000), and stripping ratios.

PEATLAND INVENTORY*

A. R. Anderson and W. Broughm

INTRODUCTION

Peat is a safe, clean, indigenous energy resource and has become one of the main options in many countries around the world to reduce their dependency on foreign oil. The production of energy from peat has been a long established technology in northern Europe where it is used as a fuel for steam generation in the production of heat and electricity. Only within the past decade has peat been recognized as a viable local energy resource in North America. Canada and the United States have been carrying out research complementing work in Europe to upgrade the production of energy from local reserves.

Information on organic soils extracted from the soil surveys of each county in Nova Scotia (Nova Scotia Soil Survey Reports, 1945-1973; Canada Department of Agriculture and Nova Scotia Department of Agriculture) indicates that the peat resources of the Province are in the range of 160 000 ha.

In stride with Nova Scotia's goal for energy independence, the Energy Resources Division has been engaged in a program since 1979 to assess the peat resources of the Province with emphasis on the availability of peat as a fuel for thermal generation.

Peat deposits can be found in almost all regions of the Province, however, there are several areas where considerable concentrations of peatlands occur (Fig. 1). The largest of these areas, located in southwestern Nova Scotia, contains approximately 38 000 ha of peatland. Other large concentrations are located in Guysborough County and eastern Cape Breton Island.

AREAS INVESTIGATED

Southwestern Nova Scotia

This region was first investigated in 1980, and by November 1982, a total of 16 725 ha of peatland had been evaluated, revealing a total assessed volume of 370 million m^3 of in situ peat. Relative tonnages of peat at 50 per cent moisture content are in the order of 24.[illegible] and 39.7 million t for horticultural grade (H_{1-4}) peat and fuel grade (H_{5-10}) peat respectively. These tonnages indicate that 62 per cent of the peat evaluated in this region has been classified as suitable fuel peat.

Specific data on the 6606 ha of peatland inventoried during the 1982 field season are still undergoing review and will be completed in 1983. Work was carried out on 43 deposits by both grid and traverse methods in Yarmouth, Queens and Shelburne Counties; however, efforts were concentrated in Queens and Shelburne Counties because of the large proportion of peatland in these regions (Fig. 2).

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*Contribution to Canada-Nova Scotia Co-operative Mineral Program 1981-84. Project carried by Nova Scotia Department of Mines and Energy.

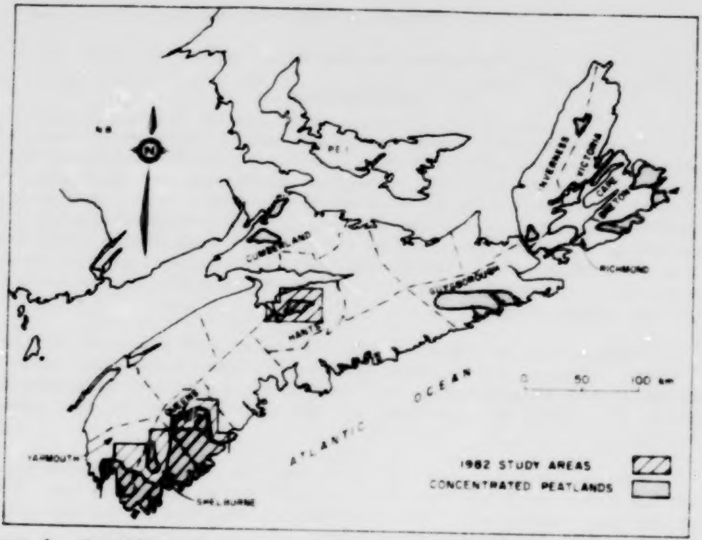
N.B.
P.E.I.
INVERNESS
VICTORIA
CAPE BRETON
RICHMOND
CUMBERLAND
GUYSBOROUGH
HANTS
ATLANTIC
OCEAN
0 50 100 km
YARMOUTH
SHELBURNE
1982 STUDY AREAS
CONCENTRATED PEATLANDS

Figure 1. Location map showing peatland areas in Nova Scotia and the 1982 study areas.

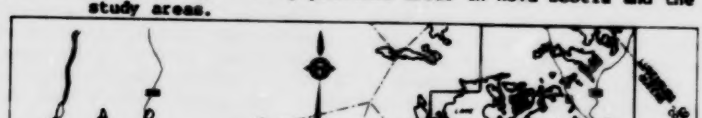
DIGBY CO
YARMOUTH CO
LIVERPOOL
LEGEND
100 500 1000
AREA (hectares)
STUDY AREA BOUNDARY
PEATLAND AREA
PEATLAND STUDIED, 1982
DISTANCE 0 5 10 15 km

Figure 2. Areas studied in 1982 field program.

The field work for the southwestern counties is completed and efforts are being directed towards final mapping and development of utilization schemes.

The volume of peat in this region is in the vicinity of 800 million m^3 (143 million t at 50 per cent moisture content) of which 60-65 per cent falls into a suitable fuel peat category (Table 1).

Halifax County

In addition to deposits in the Moose River area studied in 1981, some deposits in the Port Dufferin-West Quoddy area, Halifax County were assessed in 1982. These deposits totalled 38 ha and on the average were quite deep (up to 5.5 m). The total volume of these deposits is 1.2 million m^3 (180 000 t at 50 per cent moisture content) of which 44 per cent by weight has been identified as fuel grade peat.

Further field work is planned for the Halifax County and the Guysborough County peatland concentrations in 1983. The results will be available as reports in 1984.

Hants County

A total of 12 deposits representing 2237 ha of peatland were inventoried during the 1982 summer field program in Hants County (Fig. 3).

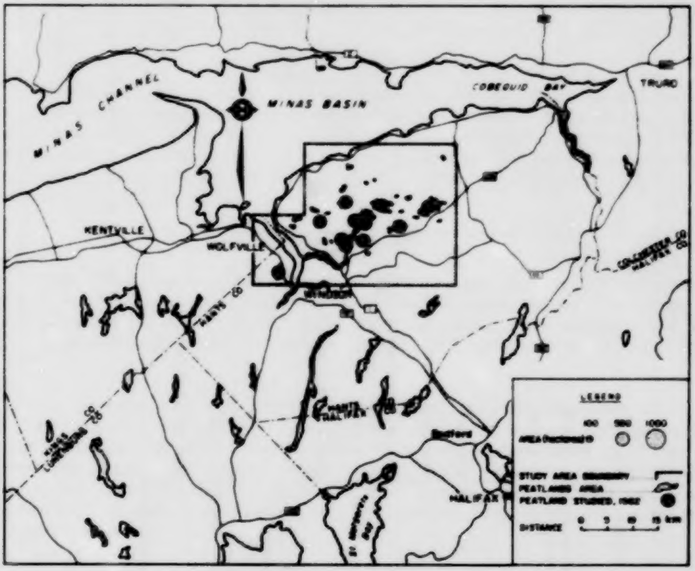
MINAS CHANNEL
MINAS BASIN
COBEQUID BAY
TRURO
KENTVILLE
WOLFVILLE
WINDSOR
HANTS CO
KINGS CO
LUNENBURG CO
HANTS CO
HALIFAX CO
COLCHESTER CO
HALIFAX CO
Bedford
HALIFAX
LEGEND
100 500 1000
AREA (hectares)
STUDY AREA BOUNDARY
PEATLAND AREA
PEATLAND STUDIED, 1982
DISTANCE 0 5 10 15 km

Figure 3. Areas studied in Hants County.

Table 1. Summary data.

Region	Year	Area Covered (ha)	Average Depth (m)	In situ Volume ($\times 10^6$ m^3)			Tonnage ($\times 10^6$) at 50% Moisture Content*			Per Cent Fuel Peat	
				H_{1-4}	H_{5-10}	Total	H_{1-4}	H_{5-10}	Total	Volume	Tonnage
Southwestern Nova Scotia	**1980	3 614	1.92	29.2	44.8	74.0	4.3	8.5	12.8	61	67
	***1981	6 505	1.79	56.8	78.4	135.2	8.3	14.9	23.2	58	64
	1982	6 606	2.59	79.1	85.9	165.0	11.6	16.3	27.9	52	58
	Average		2.10							56	62
	Resource Investigated	16 725		165.1	209.1	374.2	24.2	39.7	63.9		
	Resource Estimated	38 000		352	446	798	53	90	143	56	63
Hants County	1982	2237	3.24	51.0	29.0	80.0	7.5	5.5	13.0	36	43
	Resource Estimated	5851		112.3	77.2	189.5	16.4	14.7	31.1	41	47
Halifax County	***1981	225	3.06	6.1	0.7	6.8	0.9	0.1	1.0	10	13
	1982	38	3.09	0.8	0.4	1.2	0.1	0.08	0.18	33	44
Kings County	1982	504	2.19	5.49	5.54	11.03	0.8	1.05	1.85	50	57
	Resource Estimated	4451		48.5	49.0	97.5	7.08	9.30	16.4	50	57

*Tonnes at 50% moisture content have been calculated using the following conversion factors

H_{1-4} peat 0.146 t per in situ m^3
H_{5-10} peat 0.190 t per in situ m^3

These values have been abridged from: Montreal Engineering Co. Ltd. (1980)

**Anderson and Broughm (1981)
***Anderson and Broughm (1982)

The deposits revealed approximately 80 million m^3 of peat of which 36 per cent was classed as fuel grade peat (H_{5-10}). The deposits in this region averaged 3.2 m in depth reaching 8 m in some locations. Data from these deposits show large amounts of moss peat which makes them good candidates for horticultural peat moss production.

Estimates for the entire County show nearly 190 million m^3 of peat, 60 per cent of which would be suitable horticultural grade (H_{1-4}) peat.

Kings County

The deposits, studied in the early part of the field season, in Kings County were used to assess the fuel peat potential in the Aylesford-Berwick area.

Four bogs including the Caribou Bog (currently under peat moss production) were inventoried using a traverse system. The results show some potential for future fuel peat development on a small scale. The study covered 504 ha of peatland identifying 11 million m^3 of peat of which 50 per cent is fuel grade peat.

Estimations for Kings County of relative tonnages (at 50 per cent moisture content) for horticultural grade peat and fuel grade peat are 7.1 and 9.3 million t respectively indicating 57 per cent fuel peat by weight.

OTHER STUDIES

Climatology

During the summer of 1982 a study of the meteorological factors related to peatland exploitation methods was performed. This was achieved by researching data on sunshine, rainfall, wind patterns, relative humidity, temperature and the length of the frost free period and comparing several different sites across the Maritimes. The final report should be ready for open file in April 1983.

Remote Sensing

The Nova Scotia Department of Mines and Energy is currently engaged in a joint project with the Nova Scotia Land Survey Institute to map the peatlands of southwestern Nova Scotia. This will incorporate the use of a computerized Image Analysis system and LANDSAT (satellite) imagery.

It is expected that the maps developed through this project will provide sufficient additional information to complete a comprehensive report on southwestern Nova Scotia. The methodology developed here may be used over the entire Province using ground data gathered in successive field seasons. The final product will be a series of 1:250 000 peatland maps providing regional summaries of the extent and types of peatlands across the Province.

SUMMARY

The 1982 field program in southwestern Nova Scotia covered 6606 ha of peatland, bringing the total surveyed for the area to 16 725 ha. This represents approximately 370 million m^3 of peat, consisting of about 64 million t at 50 per cent moisture content, 62 per cent of which has been classed as a suitable fuel peat. Extrapolation of this data to cover the 38 000 ha of peatland in this region shows 800 million m^3 (143 million t at 50 per cent moisture content) of peat.

The field programs in southwestern Nova Scotia, and in Kings and Hants Counties were completed this year. Approximately 500 ha were evaluated in Kings County and 2237 ha were studied in Hants County. Supplementary field work was done on a few bogs in Halifax County in advance of the field program for next year.

Other programs this year included a climatological study and the commencement of a remote sensing project using LANDSAT satellite imagery for mapping in southwestern Nova Scotia.

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1981: Preliminary assessment of peatland resources of Nova Scotia, 1980; Nova Scotia Department of Mines and Energy, Open File Report 463.

1982: Peatland Inventory Program 1981; Nova Scotia Department of Mines and Energy, Open File Report 486.

Montreal Engineering Co. Ltd.

1980: Feasibility study for a peat-fired steam electric power with specific reference to NB New Brunswick; Canmet/Energy Mines and Resources 8-9039.

EXPLORATION ACTIVITY IN NOVA SCOTIA - 1982

J. M. McMullin

A newly created staff position for a full-time exploration-monitoring geologist was filled early in 1982, enabling increased liaison with industry and the acquisition and analysis of more detailed and meaningful statistics to show the value of mineral exploration and development to the provincial economy.

An annual survey (coloquially referred to as "Blue Forms") of all mineral resource and exploration companies was instituted in January 1982 and the results of this survey (covering 1981) are included as part of this summary (Tables 1 and 2). Total expenditures for 1981 were $14 607 662 on exploration and $8 758 567 on development, for a total of $23 366 299. This is believed to be a record, although no comparable figures exist for previous years. Table 3 shows a year-to-year comparison of exploration expenditures submitted by licensees to the Department of Mines and Energy for assessment credits. Not all expenditures are reported for assessment purposes nor do they necessarily cover any particular 12-month period or a calendar year, so there is, and will continue to be, a discrepancy between these figures and those obtained from the Blue Forms.

Levels of exploration and development activity were substantially lower in 1982 than in 1981, primarily because of the severe economic recession, but in early 1983 a noticeable improvement began which is expected to continue throughout the year, although it may be some time before activity will return to the levels of 1980 and 1981. The moratorium imposed on uranium exploration and development in September 1981 has also significantly reduced activity in the Province since that time.

Preliminary figures for exploration and development activity in 1982 indicate that expenditures in each category were reduced to about 33 per cent of the 1981 levels. Approximately 345 diamond-drill holes totalling about 23 300 m were completed in 1982 compared with 735 holes totalling 82 789 m in 1981.

Only barite showed an increase over 1981, because of the demand for drill mud in the offshore oil and gas drilling activity. Exploration for tin and tungsten in 1982 was down only slightly from 1981. Coal exploration (private and public sectors combined) was also down, but not by as much as other commodities (base metals, gold, potash, uranium, and industrial minerals).

EXPLORATION PROJECTS

Gold

During 1982, interest remained high in the Meguma-hosted Gold Districts of Guysborough and Halifax Counties and the south shore counties of mainland Nova Scotia. These gold occurrences are found principally in quartz veins, which are generally free-milling and often display spectacular visible gold. In addition a significant proportion of the gold also occurs in adjacent country rock, in arsenopyrite and other sulphides and as very finely disseminated native gold in the quartz. Many of these gold properties were worked in the latter part of the nineteenth century, with average production grades reported to be about 0.5 ounce of gold per ton, but lack of capital, inadequate or inefficient power and equipment, poor mining practice and management, together with unsuitable licensing rules and mining regulations, caused the demise of most of these operations after shallow high-grading of the most accessible parts of the veins.

There were some noteworthy exceptions but the many failures left Nova Scotia gold with a bad reputation, even though it was recognized that considerable potential remained at depth, and several productive mines were operated as deep as 1000 feet during the first half of the twentieth century, with the larger ones producing between 100 000 and 600 000 tons of ore. The last underground gold mine of any consequence, the Carbou Mine operated by Cominco, closed in 1947.

Improved gold prices have brought a renewed interest to these Nova Scotia gold properties during the last decade, to the point where exploration and development expenditures in 1981 totalled $3 791 350. Many of the approximately 50 projects in progress in 1981 were suspended or delayed during 1982 because of the severe economic recession and the low price of gold, but this situation was improving later in the year as a result of more buoyant stock markets and increasing gold prices.

Exploration in 1982 has consisted primarily of large scale trenching and stripping, detailed mapping, overburden and humus sampling, and diamond drilling. Sampling of old mill-tailings ponds in many of the former Gold Districts was carried out in 1982 to determine the feasibility of reprocessing the tailings for secondary recovery of gold.

Three test mills were constructed in 1981; two were operating at the start of 1982 and closed in late winter-early spring. The third at Harrigan Cove, Halifax County remained idle all year. The 100 tonnes per day cyanide test mill owned by Northumberland Mines Limited at Cochrane Hill, near Melrose, Guysborough County ceased operating in May 1982 after producing about 16 kg from approximately 8000 t of open-pit ore (Fig. 1). Heap cyanide leaching tests and feasibility studies were conducted during the remainder of the year, with encouraging results.

The 100 tonnes per day flotation mill erected for test purposes at Mile Lake, just 2 km west of Forest Hill, Guysborough County, treated nearly 1700 t of the nearly 5000 t of ore extracted from open cuts, before operations were suspended in March 1982 (Fig. 1). Additional work since then has consisted of more sampling and additional diamond-drilling, together with studies based on data acquired from test milling. This operation is under the management of Louisbourg Property Holdings Limited. Renewed exploration also began in the fall at Forest Hill, Guysborough

Table 1. Mineral exploration, 1981.

Commodity	EXPLORATION								DEVELOPMENT			
	Projects	Total Expenditures	Projects Drilled	Holes Drilled	Metres Drilled	Companies			Projects	Total Expenditures	Holes Drilled	Metres Drilled
						Major	Medium	Small				
Uranium	18	$ 3 699 375	9	158	17 826	6	-	-				
Potash	6	2 313 443	4	8	7 271	3	1	-				
Base Metals	41	2 203 525	12	127	14 551	8	7	6	2	$3 861 480	111*	9 491*
Gold	45	2 026 784	10	86	9 661	7	10	14	7	1 764 567	11	1 805
Coal	6	1 714 731	5	79	12 012	4	-	-	7	234 834	34	1 473
Tin & Tungsten	19	1 305 000^	3	23	1 772	5	4	-	2	1 830 300^		
Silver & Cobalt	3	324 783	1	16	2 604	2	-	-				
Barite	8	149 945	2	19	374	-	-	6				
Limestone,Dol. & Silica	5	104 350	4	55	930	-	3	-	2	1 067 386		
Salt & Gypsum	1		1	5	198	-	1	-	3		-*	1 902
Miscellaneous	4	756 726	1	3	919	2	-	2				
TOTALS	155	$14 607 662	52	579	68 118				23	$8 758 567	156	14 671

* Incomplete Data
^ Estimated

Table 2. Summary of all exploration activity 1981 (excluding "conventional" oil & gas).

REPORT OF ALL PHYSICAL WORK AND SURVEYS

PERFORMED IN THE PROVINCE OF NOVA SCOTIA

This statement is collected under the authority of the Nova Scotia Mineral Resources Act.

1 OUTSIDE OR GENERAL EXPLORATION

Type of mineral sought	Place Name, County	DIAMOND DRILLING					NATURE AND COST OF WORK PERFORMED						Please leave this column blank
		U: underground S: surface			Total Depth	Cost $	Geochemical $	Geological $	Geophysical $	Airborne geophysical $	Other works $	TOTAL $	
		Holes	S	U	Metres								
e.g. Au	*Brookfield Mines, Queens*	*6h*	*x*		*646 m*	*22 246*	*31 452*	*26 558*	*20 416*	*10 000*	*5 290*	*115 962*	
Au		86	x		9 661	595 373.70	264,071.76	291 819.08	267 338.41	170 500.00	437 681.40	2 026 784.40	
U		158	x		17 826	1 194 316.50	148 640.51	1 468 027.50	215 317.79	253 499.17	419 573.61	3 699 375.08	
Cu, Pb, Zn		127	x		14 551	722 309.02	460 492.76	373 842.56	99 675.58	105 839.00	441 367.09	2 203 526.01	
Ag, Co		16	x		2 604	212 000.00	182.41	16 000.00	15 000.00		81 600.00	324 782.41	
Li,Cs,Rb, Ta,Sn							2 189.25	1 517.00	672.00		437.75	4 816.00	
Sn, W		23	x		1 772	131 999.00	419 504.55	128 651.78	127 617.27	13 006.30	484 221.08	1 304 999.98	
N/A								3 500.00			7 410.00	10 910.00	
Barite		19	x		374	22 921.00	1 976.00	15 880.00	1 200.00		108 168.00	149 945.00	
Potash		8	x		7 372	1 470 881.13	174.00	563 943.00	241 032.35		37 611.50	2 313 642.78	
Gypsum and Silica		41	x		899	40 616.00	12 780.00	15 300.00			4 300.00	72 996.00	
Limestone & Dolomite		19	x		229	19 822.50	1 580.00	7 032.00			3 000.00	31 354.50	
Coal		79	x		12 012	1 210 345.00		17 000.00	487 386.00			1 714 731.00	
Methane fr Coal		3	x		919	207 500.00					542 500.00	750 000.00	
	TOTAL	579	x		60 119	5 028 083.93	1 311 511.24	2 902 313.72	1 495 239.40	543 844.37	2 567 670.45	14 407 663.06	

2 MINE OR ON-PROPERTY EXPLORATION

Type of mineral sought	Place Name, County	DIAMOND DRILLING					NATURE AND COST OF WORK PERFORMED						Please leave this column blank
		U: underground S: surface			Total Depth	Cost $	Geochemical $	Geophysical $	Geological $	Airborne geophysical $	Other works $	TOTAL $	
		Holes	S	U	Metres								
Au		11	x		1 805	96 027.00	13 430.00	14 000.00	(x) 42 996.00			166 453.00	
Cu, Pb, Zn		111*	x (73)	x (38)	9 491*	359 886.00						359 886.00	
Salt & Gypsum		10*	x	x	1 252	77 695.00			720.00			78 415.00	
Coal		13	x		807	107 000.00		3 820.00	11 000.00			121 820.00	
	TOTAL	145			13 355	640 608.00	13 430.00	17 820.00	54 716.00			726 574.00	

* Incomplete data (x) Includes engineering

3 MINE OR ON-PROPERTY DEVELOPMENT

Type of mineral sought	Place Name, County	DIAMOND DRILLING					SHAFT		DRIFTS AND CROSSCUTS		RAISES AND DECLINES		Stripping $	Other $	TOTAL $	Please leave this column blank
		U: underground S: surface			Total Depth	Cost $	Depth	Cost $	Length	Cost $	Length	Cost $				
		Holes	S	U	Metres		Metres		Metres		Metres					
Au							18.49	11 920	16	2 550	8	400	5 510	(y) 1 577 733	1 598 113	
Cu, Pb, Zn									2694.3	3 448 569	67	53 025			3 501 594	
Sn, W											1 000	1 700 000		130 305	1 830 305	
Salt,Gypsum Limestone		*			650	*			154	72 049	16	16 900	877 927	22 095	988 971	
Coal		21	(19)	(2)	666.5	101 608								11 406	113 014	
	TOTAL	21			1 316.5	101 608	18.49	11 920	2864	3 523 168	1 091	1 770 325	883 437	1 741 539	8 031 997	

* Incomplete Data (y) Includes Construction

Table 3. Mineral exploration trends in Nova Scotia

	1976	1977	1978	1979	1980	1981	1982
Exploration Expenditure ($)*	1 600 000	3 800 000	5 900 000	4 700 000	7 564 000	8 441 270.30	4 287 273.20
Total Licences Issued	1 489	2 894	2 393	1 841	2 559	1 896	1 205
Claims Recorded							
General (base metals, gold, etc.)	35 434	70 936	38 597	40 497	88 703	72 907	40 084
Uranium	21 526	48 721	31 978	30 920	25 483	6 225	0
Salt, Potash	224	887	1 148	2 256	13 505	1 155	656
Coal							3 072
No. Mineral Assessment Reports	70	95	132	126	140	157	124

*Based on assessment work submitted to Department of Mines and Energy each year.

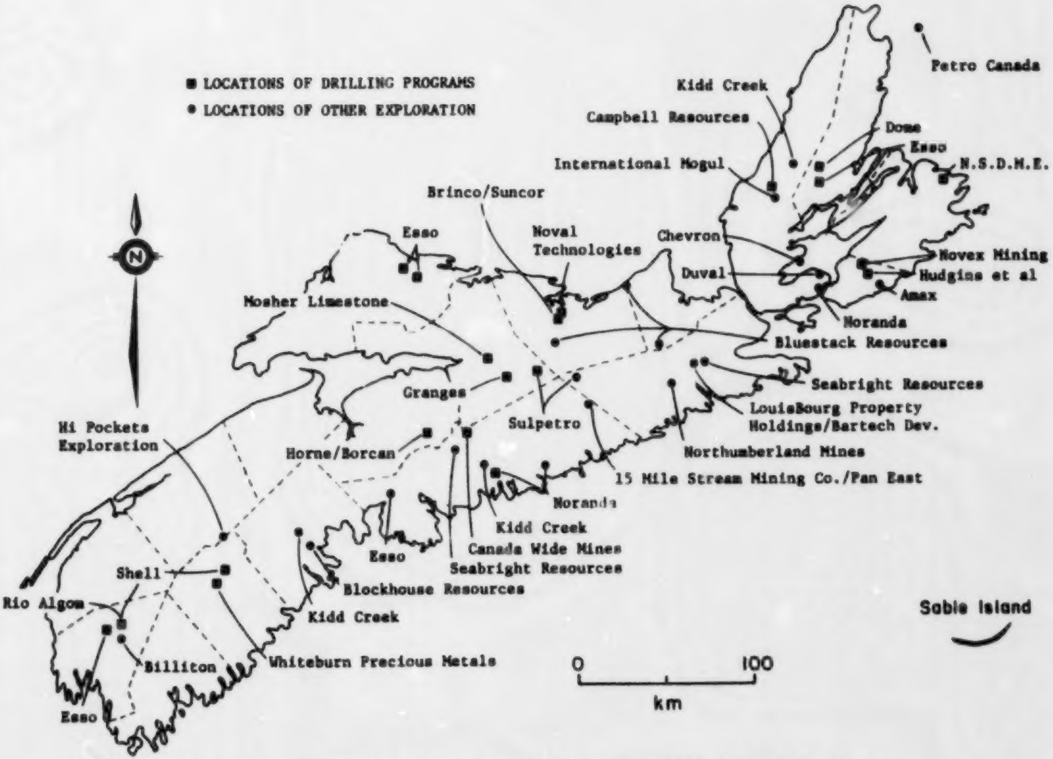

■ LOCATIONS OF DRILLING PROGRAMS
● LOCATIONS OF OTHER EXPLORATION
N
Petro Canada
Kidd Creek
Campbell Resources
Dome
Esso
N.S.D.M.E.
International Mogul
Brinco/Suncor
Esso
Noval Technologies
Chevron
Novex Mining
Hudgins et al
Duval
Amax
Mosher Limestone
Noranda
Bluestack Resources
Seabright Resources
Granges
LouisBourg Property Holdings/Bartech Dev.
Sulpetro
Hi Pockets Exploration
Northumberland Mines
Horne/Borcan
15 Mile Stream Mining Co./Pan East
Noranda
Kidd Creek
Canada Wide Mines
Esso
Seabright Resources
Shell
Blockhouse Resources
Rio Algom
Kidd Creek
Sable Island
Billiton
Whiteburn Precious Metals
0
100
km
Esso

Figure 1. Mineral exploration for 1982 in Nova Scotia.

County (Fig. 1). This work consisted of large scale overburden and rock trenching, geophysics, diamond-drilling and detailed geological mapping, and was under the direction of Seabright Resources Inc.

Fifteen Mile Stream Mining Company trenched several sites of Fifteen Mile Stream, Halifax County (Fig. 1) and this property was subsequently acquired by Pan East Resources Inc. Whiteburn Precious Metals Limited and Louisbourg Property Holdings Limited carried out sampling programs and diamond-drilling in the Whiteburn Gold District near Caledonia, Queens County (Fig. 1).

Limited underground development work was carried out by Edgar Horne and Byron Taylor at Renfrew, Hants County(Fig. 1), along with a diamond-drilling program conducted by Borcan Resources. Diamond-drilling was also performed by Noranda Exploration Company Limited for precious metals associated with base metals at the Dunbrack prospect near Musquodoboit Harbour, Halifax County (Fig. 1). Exploration also began late in the year on ground held by Blockhouse Resources in the Blockhouse Gold District near Mahone Bay, Lunenburg County. All the other former Gold Districts in the Meguma Group were held under exploration licences but received only limited activity.

Dome Exploration did detailed geochemical surveys and diamond-drilling at Second Gold Brook, Victoria County on Cape Breton Island (Fig. 1), a gold property not in the traditional Meguma hosted Gold Districts of mainland Nova Scotia.

Base Metals

Tin and tungsten exploration continued during 1982, principally in mainland areas underlain by specialized granites of Ordovician age and in adjacent areas. The main focus of interest continues to be the Yarmouth County area where the East Kemptville tin deposit was discovered and outlined by Shell Canada Resources Limited during 1978-1981 (Fig. 1). It is a low-grade (0.2% Sn) greisen hosted deposit with reserves calculated at 38 million t. An intensive exploration program of overburden reverse circulation drilling and diamond-drilling was carried out by Shell to complete work commitments on areas surrounding the orebody before they disbanded their Mineral Division in June 1982. The tin orebody and surrounding exploration licences were purchased by Rio Algom Limited in the fall of 1982 and by year-end further detailed diamond drilling was under way on the orebody to obtain metallurgical samples.

Shell also carried out geophysical surveys and diamond-drilling for tin and tungsten at Caledonia, Queens County (Fig. 1) in the spring of 1982, and this property, along with most of the remainder of the Shell base metal exploration licences, was taken over by Billiton Canada Limited in the fall. Billiton also staked a very large area (8000 new claims) of ground in Yarmouth and Shelburne Counties.

Esso Minerals continued exploration consisting of geology, geochemistry, geophysics and diamond-drilling on its joint-venture tin-tungsten prospect at Pearl Lake, Yarmouth County (Fig. 1) and also explored a block of ground at Tantallon, Halifax County.

Kidd Creek Mines focused most of their exploration work on tin and tungsten during 1982 with the emphasis on geological and geochemical work. Areas covered include the Whale Lake and Wallaback Lake areas of Lunenburg County, the Musquodoboit batholith, Halifax County and parts of Queens and Shelburne Counties. Selco Inc. prospected for tin and tungsten in Cape Breton Island and Noranda Exploration Company Limited looked at the Ship Harbour area, Halifax County (Fig. 1).

Copper, lead and zinc exploration was at a somewhat reduced pace with the emphasis on Carboniferous sedimentary environments. Some work was carried out in igneous and metamorphic terranes, particularly on Cape Breton Island. Esso Minerals, Bluestack Resources, Noranda Exploration, and Sulpetro Minerals were the most active. More diamond drilling was done on Esso's Pugwash area claims in Cumberland County, on Sulpetro's Meguma-hosted prospect near Eastville, Colchester County, and by Granges Exploration on the old Smithfield mine area near Middle Stewiacke, Colchester County, where EM geophysical surveys were also carried out (Fig. 1). Sulpetro completed an overburden sampling program near Trafalgar, Guysborough County. Bluestack Resources were busy on their joint venture program with Selco in northeastern mainland Nova Scotia, where several areas were subjected to overburden sampling, geochemical surveys and geological work in the search for base metals and barite (Pictou and Antigonish Counties, Fig. 1). Noranda drilled on Gillis Mountain, Cape Breton County and Dunbrack (Musquodoboit Harbour), Halifax County prospects, and Esso drilled in the Middle River area, Victoria County. Also in Cape Breton, Mineral Tech carried out geochemical, geological and geophysical surveys on a group of claims in the Woodbine-Marion Bridge area underlain by Windsor sediments. Amax performed some geophysical work in the Precambrian and Cambrian sedimentary/volcanogenic terrane southwest of Framboise, Richmond County (Fig. 1).

At year end, Cuvier Mines Inc. in association with Campbell Resources was drilling in the Carboniferous near Burlington, Hants County to evaluate a base metals/barite target.

The underground lead-zinc mine of Canada Wide Mines (Esso) at Gays River closed permanently in July 1982 because of insurmountable problems with bad ground and because of irregularities in the ore body. Some surface diamond-drilling was done to help evaluate the potential for open-pit production.

Barite

Occurrences of barite are common in Nova Scotia and are well documented in Nova Scotia Department of Mines and Energy Bulletin No. 4. One mine at Brookfield, Colchester County produces pharmaceutical grade barite from a deposit on the Horton-Windsor contact in Carboniferous sediments. In a similar geological environment at Pine Brook, Cape Breton County, Novex Mining and Exploration has been drilling and trenching in preparation for open-pit mining to supply mud-grade barite for the offshore hydrocarbon exploration industry. The former Yava Mines mill (previously Kaiser Celestite) at Lake Enon was purchased for beneficiating the barite.

The barite/fluorite deposits in the Trout Brook and Scotsville areas on the eastern side of Lake Ainslie in Inverness County also received further attention during 1982. These vein deposits occur in Carboniferous volcanics, Devonian intrusives and Precambrian metamorphics. Campbell Resources (CCH Minerals) carried out an intensive geochemical sampling, trenching and diamond-drilling program at Scotsville with encouraging results. At Trout Brook the Conwest group (International Mogul Mines and New Mount Costigan Mines) took out a bulk sample for metallurgical testing (Fig. 1).

Cuvier Mines in association with Campbell Resources were drilling for barite in the Horton-Windsor contact zone near Burlington, Hants County and Bluestack Resources was investigating several barite targets in Pictou and Antigonish Counties; both programs were also involved with base metal exploration.

Potash

Exploration for potash in the Carboniferous Basins was very limited in 1982 and no drilling was carried out. Cominco postponed plans to drill near Kennetcook, Hants County and Chevron Canada dropped their licences in the Bras d'Or Lake area of Cape Breton Island. Earlier in the year, Chevron carried out a gravity survey in the West Bay area of the Lake (Fig. 1). Nearby Noranda Exploration Company Limited did not renew their licence in the St. Peters' area of Richmond County although geological mapping was carried out there and further work was done to evaluate their Ashfield licences. Total expenditures for potash exploration in 1982 were greatly reduced from the $2.3 million spent in 1981.

Limestone

Mosher Limestone has been actively seeking new sources of agricultural dolomitic limestone and carried out diamond-drilling in the East Mountain area near Truro, Colchester County (Fig. 1). Mosher Limestone also intends to open up a dolomite quarry at Gays River. Canada Cement Lafarge did some drilling to outline reserves at the Brookfield quarry in Colchester County.

Silica Sand

Evaluation drilling was carried out by the Department on thick sand deposits of Cretaceous age at Diogenes Brook near Melford, Inverness County and in the Musquodoboit Valley, Halifax County.

Coal

Brinco continued deep drilling in the Westville-Stellarton area, Pictou County during the early part of the year and this exploration program was later continued by Brinco's joint venture partner Suncor, who carried out a seismic survey for subsurface structural analysis (Fig. 1).

The Department continued drilling on the Tracy and Gardiner seams in the Sydney coalfield and at Springhill, Cumberland County.

Petro-Canada studied data obtained from a previous seismic survey over their offshore licences near Aspy Bay, Northern Cape Breton Island (Fig. 1).

Methane

Noval Technologies continued to test and evaluate several wells drilled for potentially commercial demethanation of coal seams in the Pictou coalfield, and drilled another test well in New Glasgow, Pictou County (Fig. 1) during the summer. Testing is continuing.

GENERAL ACTIVITY

Table 3 shows that although active exploration was considerably reduced from recent years, the amount of ground held under licence was still at a very good level. Staking activity was increasing toward the end of the year implying a turnaround in exploration activity.

Several companies previously active in the Province faded from the scene. Both Shell Canada Resources Limited and Gulf Minerals Canada Limited disbanded their minerals exploration divisions and Amax Minerals closed their regional office in Sackville, New Brunswick to undergo a reorganization. Saarberg Interplan Limited, whose sole business is uranium exploration, was unable to carry out any work in Nova Scotia, and Kidd Creek Mines Limited was restricted from its former activities because of the uranium moratorium. Chevron Canada Resources Limited dropped all of its licences during the year. International Mine Services Limited, the Joe Hirschhorn exploration group, dropped their remaining claims and terminated their presence in the Province after carrying out exploration throughout the 1970's. Sheritt Gordon Mines Limited and the Northgate-Patino group also dropped their claims and/or terminated options. Many other companies suffered varying degrees of trauma during the year because of budget cuts.

Companies opening offices in Nova Scotia during 1982 included Selco Inc. and Billiton Canada Limited, both in the Halifax-Dartmouth area. Rio Algom Limited now maintains a field office in East Kemptville.

Among other large companies coming into the Province for the first time or after a period of absence, or who have been increasing their activities, are Asarco Exploration Company of Canada Limited, the Sullivan Mining Group and Campbell Resources Inc. Approximately 300 individuals, companies and groups held mineral licences in Nova Scotia during 1982.

DRILL CORE LIBRARY

J. M. Bingley

Until recently, government core storage programs were given a rather low priority by most provincial governments. This priority changed however, at the 37th Annual Conference of Provincial Ministers of Mines (1980), when a report from the Standing Committee of Provincial Geologists strongly endorsed the principle of government involvement in these programs. Subsequent to that meeting both federal and provincial funds have become more readily available for implementation of core storage programs.

Nova Scotia had maintained some core storage capacity for many years, but space was not available to retain more than the amount of core generated by our own drilling division. This cumulative amount together with some company core, is approximately 76 200 m of core that is partially stored outdoors. In anticipation of additional protected space being available, and to facilitate rapid handling of cores, a fork-lift truck was purchased in 1979. It was not until a federal-provincial agreement provided funding in late 1981 however, that new buildings could be planned and retrieval of company cores could begin. As of Autumn 1982 approximately 60 960 m of company drill cores have been assembled awaiting the building of new facilities.

The new facility, now nearing completion in Stellarton, consists of three steel-clad arch rib structures each measuring 15.8 m by 48.8 m (Fig. 1). The combined core capacity will be approximately 304 800 m. All core will be stored on pallets and catalogued by the NTS system.

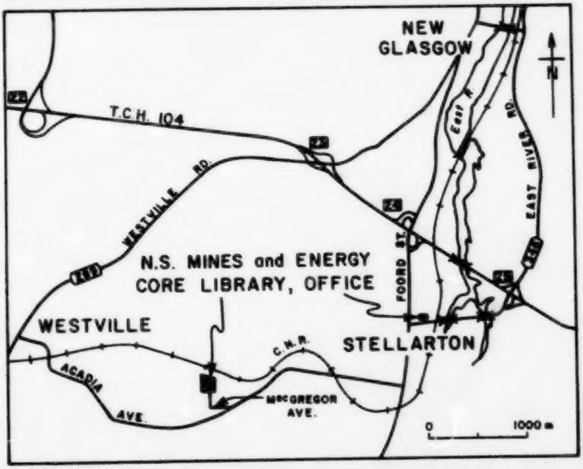


Figure 1. Location of the Nova Scotia Department of Mines and Energy core library and Stellarton office.

To minimize man-handling heavy boxes, individually complete holes will be transported by fork lift truck to a 111 m^2 laboratory incorporated into the first building. Large, roller-topped examination tables will permit rapid movement of core boxes. The laboratory will be the only part of the buildings that will be heated. Core splitters, diamond saws, a low power microscope and related laboratory equipment will be available at this location.

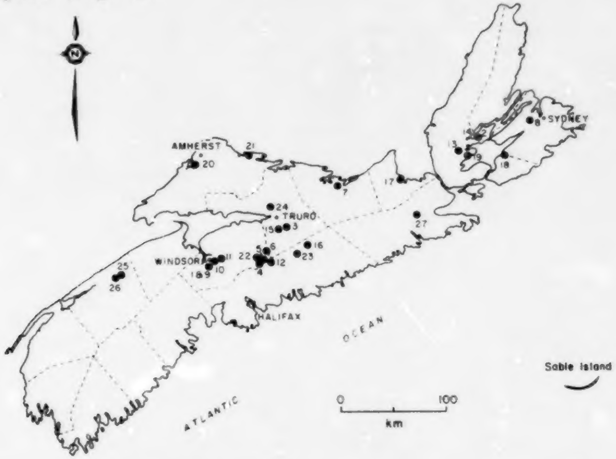
As mentioned previously core will be stored on pallets and indexed by NTS map number (e.g. 11E/10A) and where possible by tract and claim as well. An individual file card will be kept for each hole and this card will indicate the place name, the company that had the drilling done, the company's hole designation, the drilling company, the depth of the hole, and other pertinent data. Core logs will be kept on file if they are available in assessment reports or made available from other sources.

In addition to the above-mentioned information that will be retained in the storage facility, a catalogue will be kept that lists all of the drill cores stored and considerable pertinent data. This catalogue will be updated annually and made available to the public.

INDUSTRIAL MINERALS*

J. H. Fowler

Overall production value of industrial mineral commodities for 1982 is expected to be lower than 1981 because of the downturn in the economy. This lull in activity offered many producers an opportunity to explore for new deposits, formulate development plans for reserves or probe the possibilities of expansion into other commodity markets. Commodities receiving such attention include gypsum, limestone, dolomite, silica sand and aggregates (Fig. 1).



INDUSTRIAL MINERAL PRODUCERS

ANHYDRITE
1,10. Fundy Gypsum Co. Ltd.
2. Little Narrows Gypsum Co. Ltd.

BARITE
3. Nystone Chemicals Ltd.

CLAY AND SHALE
4-7. L. E. Shaw Ltd.

DOLOMITE
8. Scotia Limestone Ltd.

GYPSUM
9-10. Fundy Gypsum Co. Ltd.
11. Domtar Construction Materials
12. National Gypsum Canada Ltd.
13. Georgia Pacific Corp. Bestwall Division
14. Little Narrows Gypsum Co. Ltd.

LIMESTONE
15. Canada Cement Lafarge Co. Ltd.
16. Mosher Limestone Co. Ltd.
17. Ridge Brokers Ltd.
18. Scotia Limestone Ltd.
19. Nova Scotia Sand and Gravel

SALT
20. Sifto Salt Division, Domtar Chemicals Group
21. Canadian Salt Company Ltd.

SILICA SAND
22-24. Nova Scotia Sand and Gravel

STONE
25. Heritage Memorials
26. A. & R. Nixon Granite Works Ltd.
27. Arsenault Monumental Works Ltd.

Figure 1. Industrial mineral producers in Nova Scotia, 1982.

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*Contribution to Canada-Nova Scotia Co-operative Mineral Program 1981-84. Project carried by Nova Scotia Department of Mines and Energy.

NSDME Report 83-1

Barite highlights industrial mineral exploration activity. Local demand is at an all time high because of offshore oil and gas well drilling. Most of the known barite occurrences have been started with exploration programs underway at several locations. Activities directed toward known barite deposits include metallurgical testing and market analysis.

CRETACEOUS PROJECT

This is a project to ascertain the stratigraphy, relationship to bedrock and economic significance of the Cretaceous clay and silica sand deposits of central mainland Nova Scotia and southern Cape Breton.

In March of this year, Federal funds provided through a Federal-Provincial Mineral Development Agreement allowed for the completion of two diamond-drill holes in Cretaceous sediments at Elmsvale, Halifax County. This is significant in that it was the first time these deposits were "cored" from top to bottom. On the northern side of the Musquodoboit Valley, DDH PB82-1 intersected refractory grade clay interbedded with silica sand from 3.4 m to 113.0 m . Bedrock at 113.0 m was laminated gypsum and limestone. South of the Musquodoboit River DDH EL82-1 intersected similar deposits from 9.0 m to 81.7 m. Intercalated mudstone, siltstone and limestone occurs below 81.7 m (Fig. 2).

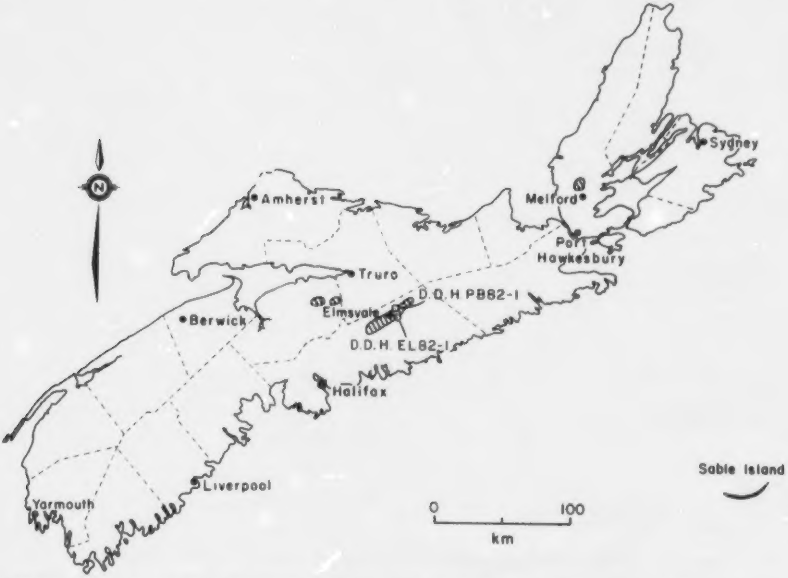

Figure 2. Areas of Cretaceous clay and silica sand deposits and location of two drillholes at Elmsvale, Halifax County.

In May a geologist was hired under contract to continue the Cretaceous program. To date all known silica sand deposits have been sampled for heavy mineral analysis, sieve analysis and petrographic work. A total of 13.3 km of refraction seismic work has been completed along six lines across the Musquodoboit Valley in the Middle Musquodoboit-Elmsvale district of Halifax County. Results show the depth to bedrock at Elmsvale varies from 18 m to 167 m over a horizontal distance of 300 m. The depth to bedrock is greatest along the northern side of the valley. A diamond-drill program is slated for the deepest sections of the valley to determine the thickness and stratigraphy of the Cretaceous deposits. At Diogenes Brook (Glen Brook) in the vicinity of Melford, Inverness County diamond drilling is underway on suspected Cretaceous deposits found in the valley of the Brook.

Contributing significantly to the understanding of the Cretaceous deposits of Nova Scotia is the palynological work on core samples from the two drillholes completed at Elmsvale earlier this year. This work is being done by the Eastern Petroleum Geology Section of the Atlantic Geoscience Centre at the Bedford Institute of Oceanography.

A report is being prepared on the Cretaceous deposits of Nova Scotia.

AGGREGATE RESOURCES OF SOUTHWESTERN NOVA SCOTIA*

W. J. Wright

The purpose of this survey is to identify all granular and bedrock aggregate resources within the study area. It is the intention of this survey to provide information on the location, quality and quantity of extractable materials and to identify bedrock sites suitable for aggregate quarry operations. The 1982 and 1983 study areas are shown on Figure 1.

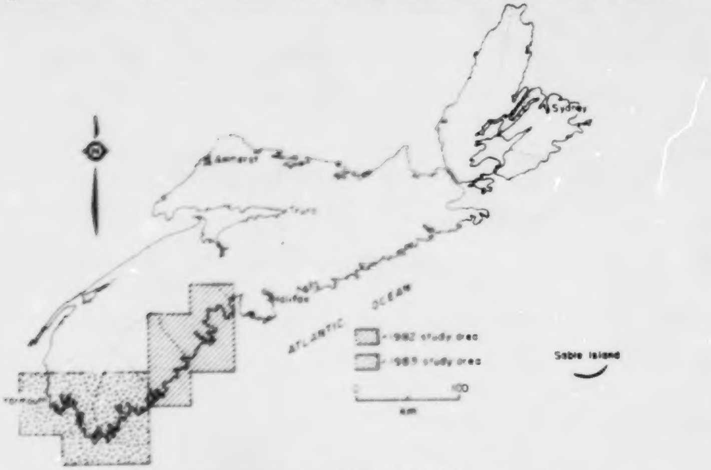

Figure 1. Locations of the 1982 and 1983 study areas.

Available information on the surficial geology of the study area such as aerial photographs, theses, assessment files (diamond-drill hole logs), bedrock geology maps, and aggregate producer data has been researched.

The glaciofluvial and bedrock samples collected will be tested for soundness, abrasion resistance, organic content and size gradings.

Geophysical work such as resistivity or seismic may be employed at a later date to help assess certain deposits.

Information gathered during the field season has been plotted on 1:50 000 NTS map sheets and the final product will consist of 1:100 000 scale maps with a report.

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*Contribution to Canada-Nova Scotia Co-operative Mineral Program 1981-84. Project carried by Nova Scotia Department of Mines and Energy.

MINERAL INVENTORY AND LIBRARY*

N. A. Lyttle

REPORTS PUBLISHED IN 1982

Over the past two years, we concentrated our activities upon entering and updating NSDME document data in GEOSCAN, the national bibliographic data base for geological information. As a result of these efforts, we published eight reports in 1982. These reports are:

Report 81-4	*Index to Assessment Reports 1864-1980*
Report 81-5	*Keyword Index to Assessment Reports in NSDME Report 81-4*
Report 81-6	*Index to NSDME Publications, Open File Reports and Theses 1862-1980*
Report 81-7	*Index to Drillhole and Well Data 1862-1980*
Report 82-2	*Index to Assessment Reports 1981 (with Keyword Index)*
Report 82-3	*Keyword Index to Publications in NSDME Report 81-6*
Report 82-4	*Keyword Index to Open File Reports in NSDME Report 81-6*
Report 82-5	*Keyword Index to Geological Survey of Canada Documents on Nova Scotia to 1980*

REPORTS IN PREPARATION

Early in 1983 we expect to publish the Index to Assessment Reports for 1982, and the Index to NSDME Publications, Open File Reports, Theses and Geological Survey of Canada Documents on Nova Scotia for 1981 and 1982.

CANADA-NOVA SCOTIA CO-OPERATIVE MINERAL PROGRAM 1981-1984

Funds were obtained to finance three new projects in 1982 through a new Federal-Provincial agreement, the Canada-Nova Scotia Co-operative Mineral Program 1981-1984. Funds from the Canada Department of Energy, Mines and Resources and the Province of Nova Scotia are financing the GEOSCAN Updating Project; funds from the Canada Department of Energy, Mines and Resources are financing the Metallic Minerals Updating Project; and funds from the Province of Nova Scotia are financing the Drillhole Database Project.

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*Contribution to Canada-Nova Scotia Co-operative Mineral Program 1981-84 Project carried by Geological Survey of Canada and Nova Scotia Department of Mines and Energy

GEOSCAN Updating Project

David Hopper was hired on contract to code and enter into GEOSCAN the subject contents of all geoscience theses on Nova Scotia that are cited in *Report 81-6 Index to NSDME Publications, Open File Reports and Theses 1862-1980*. All theses cited in *Report 81-6* are being acquired on microfilm to form a public reference file in the Halifax office library. A map showing the locations of thesis study areas in Nova Scotia is also under preparation. In addition, all journal literature on the geoscience of Nova Scotia will be coded and entered into GEOSCAN. Two computer terminals, required for on-line data entry into GEOSCAN, have been rented for two years using Energy, Mines and Resources' funds, under the terms of this agreement.

Metallic Minerals Updating Project

Karen White-Smith was hired on contract to update the manual metallic mineral occurrences database. This project involves the checking and updating of previously compiled metallic mineral occurrences cards, and compiling new cards from a variety of post-1977 documents. Ultimately, it is hoped that the manual metallic mineral occurrences database will be entered into a computer-based data management system, and be available for on-line searching and data retrieval.

Drillhole Database Project

Report 81-7 Index to Drillhole and Well Data 1862-1980 lists by map sheet the titles of all NSDME documents (Assessment Reports, Open File Reports and Publications) that contain information on drilling in Nova Scotia. The majority of these titles refer to drilling on land for mineral exploration. *Report 81-7* provides sources of drilling information but not the actual drilling data. To provide a means of storing and rapidly retrieving, sorting and manipulating the drillhole data in the documents cited in *Report 81-7*, a computer based drillhole database was developed with the co-operation of the Information Division of the Maritime Resource Management Service.

For each drillhole, data are recorded under the following twenty-eight parameters: NTS Map, NSDME Drillhole Number, Claim Reference Map, Tract, Claim, County, UTM Zone, Easting, Northing, Latitude, Longitude, Mineralization, Commodity, Assay, Reference, Licensee, Exploration Company, Company Drillhole Number, Drilling Company, Year Drilled, Hole Depth, Collar Elevation, Penetration, Drillhole Sample Type, Drillhole Sample Location, Drillhole Logs, Drillhole Sections, and Paleontology. The database can be searched on all of these parameters, or any combination of individual parameters, and the resulting information printed out at a computer terminal. In addition, by using a drum plotter, computer generated drillhole location maps at variable scales can be produced. For example, a tabular printout for all twenty-eight parameters could be obtained for all drillholes on map 11D/12, and an outline map generated with all the drillholes for that map area plotted on it. A more narrowly defined search could be used to identify and printout data on drillholes containing gold mineralization on map 11D/12 with the generation of the corresponding drillhole location map.

The coding and data entry for this drillhole project commenced in the summer of 1982 with the hiring of two summer students. Because of the large numbers of drillholes involved, our coding efforts were confined to drillholes described in the assessment reports cited in *Report 81-7* . To date, coding and data entry have been completed for all drillholes in map sheets 11D, 11E/01, 11E/02, 11E/03, 11E/04, 11F/03, 11F/04, 11F/05, 11F/06, 11F/07, 11F/09, 11F/10, 11F/11, 11F/12 and 11F/13.

LIBRARY

During 1982 renovations to the library resulted in major improvements which directly benefit users of the library. Floor space nearly doubled, and new shelving for our collections and periodicals, and arc files for maps were installed. Two new microfilm reader-printers were purchased, and all three reader-printers were housed in individual study carrells to provide more privacy.

In 1981, a contract librarian was hired to catalogue and classify our library holdings. This activity is continuing, and to date approximately 50 per cent of our holdings have been catalogued and classified. A card catalogue now exists for the library holdings, providing author/title and subject files, thus facilitating rapid access to a wide variety of geoscience reference material.

ASSESSMENT REPORTS AND OPEN FILE REPORTS FOR 1982

By the end of 1982, an additional 134 Assessment Reports and 55 Open File Reports became open. All these reports have been microfilmed and they can be consulted in the libraries of the Halifax and Stellarton offices. These reports can also be purchased on microfiche directly from Precision Microfilming Services, 6061 Young Street, Halifax, Nova Scotia, B3K 2A3 (902 455-5451). Lists of the 1982 Assessment Reports and Open File Reports are published as Appendices I and II in this Report of Activities.

TECTONIC STUDIES

J. D. Keppie

The Tectonic Map of the Province of Nova Scotia was published during 1982 at a scale of 1:500 000. The Lineament Map of Nova Scotia, at a scale of 1:1 000 000 was published in the corner of the Tectonic Map. Papers describing the principles used in making the Tectonic Map were published in Episodes, volume 1981, No. 4, p. 11-14 and Nova Scotia Department of Mines and Energy, Paper 81-4. A sumary of the tectonics of Nova Scotia is contained in a paper entitled *The Minas Geofracture* published in the Geological Association of Canada, Special Paper 24, 1982, the abstract of which follows on page 43 of this volume.

Also published during 1982 was the Structural Map of the Appalachian Orogen in Canada, by J. D. Keppie, A. A. Ruitenberg, L. Fyffe, S. McCutcheon, P. St. Julien, B. Skidmore, J. Béland, C. Hubert, H. Williams and J. Bursnall at the scale of 1:2 000 000, Memorial University of Newfoundland, Map No. 4. A brief paper on the *Times of Deformation in the Canadian Appalachians* will be published in the International Geological Correlation Program, Project 27, NATO Advanced Study Institute Proceedings of the conference in Fredericton, New Brunswick during August 1982. The preconference field trip guidebook for the Avalon and Meguma Zones compiled by A. F. King includes a section on Nova Scotia by J. D. Keppie and P. E. Schenk.

The Tectonic Map of Nova Scotia was presented at a poster session at the Northeastern Section Meeting of the Geological Society of America and the abstract follows on page 42 of this volume.

TECTONIC MAP OF NOVA SCOTIA*

J. D. Keppie

The Tectonic Map of Nova Scotia is displayed. It is based upon plate tectonic theory and portrays the origin and evolution of the region in space and time. Previously, tectonic maps were based upon the outdated geosynclinal theory. The advent of plate tectonics heralded a new generation of tectonic maps, however, no generally acceptable scheme has yet emerged. The scheme devised for the Tectonic Map of Nova Scotia should form the basis for other tectonic maps.

In this tectonic classification scheme, three hierarchical categories are recognized: zones, stages and elements.

A **tectonic zone** is defined as an area characterized by the nature of the underlying crust (continental, transitional or oceanic) and is bounded in time by orogenies.

A **tectonic stage** is defined as a phase of tectonic development forming part of a tectonic zone and characterized by an association of tectonic elements. The following stages are recognized: stable, rift, atlantic, pacific, and transpression stages.

A **tectonic element** is defined as a certain, specific, well-defined tectonic environment and characterized by a distinct tectono-stratigraphic or tectono-plutonic rock unit which is part of a tectonic zone or stage, e.g. continental shelf, forearc basin, marginal basin, etc.

On the tectonic map, each tectonic stage is assigned one or more colours and each tectonic element bears a shade of colour dependent upon the stage to which it belongs. The notation on the map identifies each tectonic element to its stage, zone, and terminating orogeny.

Structural elements plotted on the Tectonic Map of Nova Scotia include folds (colour-coded according to their age), faults, unconformities, structure contours, metamorphic isograds and gravity anomalies.

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*In Geological Society of America, Abstracts with Programs, 1982, v. 14, p. 30

THE MINAS GEOFRACTURE*

J. D. Keppie

ABSTRACT

The Minas Geofracture is defined as the east-west boundary between the Meguma and Avalon Zones in and adjacent to Nova Scotia. It is a deep crustal fault that separates dissimilar Precambrian and Lower Paleozoic rocks. It is inferred to have originated during the Middle Devonian Acadian Orogeny. Prior to that time, the Avalon Zone from Boston through coastal Maine and southern New Brunswick to near the Magdalen Islands is interpretated as a southwesterly strike continuation of Cape Breton Island. This palinspastic reconstruction is based upon correlation of Precambrian-Early Devonian lithotectonic and paleogeographic belts. During the Acadian Orogeny a dextral movement of at least 370 km to 475 km took place on the Minas Geofracture, followed, in Mid-Late Devonian times, by a dextral movement of at least 280 km upon a fault parallel to Chignecto Bay. Some vertical relief on the Geofracture is indicated by the presence of Mid-Late Devonian molasse only on its northern side. As a consequence of these dextral movements the Magdalen Basin formed as a complex rift where the Appalachians swing through a Z-shaped bend. During Early Carboniferous times the Minas Geofracture was generally inactive; however, initial paleomagnetic results suggest that an internally coherent block, including the Avalon and Meguma Zones, moved 1500 km to 2000 km northwards relative to cratonic North America. During the Late Westphalian to Permian Hercynian Orogeny, a dextral movement of approximately 165 km is inferred to have taken place on the Minas Geofracture and a dextral movement of approximately 95 km along Chignecto Bay. Finally, during Early Mesozoic times, a sinistral movement of approximately 75 km took place on the Minas Geofracture as the Bay of Fundy Rift formed in response to the opening of the Atlantic Ocean.

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*In Major Stuructural Zones and Faults of the Northern Appalachians, eds. P. St. Julien and J. Béland; Geological Association of Canada, Special Paper 24, 1982.

THE APPALACHIAN COLLAGE*

J. D. Keppie

ABSTRACT

A map of the northern Appalachians is presented which shows that it is made up of a collage of terranes originating outboard of cratonic North America. A terrane is defined as an area characterized by an internal continuity of geology, including stratigraphy, faunal provinces, structure, metamorphism, igneous petrology, metallogeny and paleomagnetic record, which is distinct from that of neighbouring terranes and cannot be explained by facies changes. The term composite terrane is applied to terranes which amalgamated before accretion to the continental margin. Terrane boundaries are generally faults or melanges representing sutures, now largely cryptic, with complex structural histories often involving transcurrent motions. Constraints on the time of accretion are provided by the age of the youngest strata unique to a particular terrane and the age of overstepping strata, straddling plutons, thrusts, straddling regional metamorphism and exotic pebbles. Deformation is often synchronous with accretion as a result of collision, whereas metamorphism and plutonism are generally longer lived.

Using these criteria, it is possible to unravel the accretionary history of the northern Appalachians. During latest Precambrian times, the Avalon composite terrane was formed by the collision of several terranes resulting in the Cadomian Orogeny. In Late Cambrian-earliest Ordovician times the Boundary composite terrane was formed by collision of several terranes producing the Penobscot Disturbance. During Llanvirn-Caradocian Taconian Orogeny, terranes in the northwestern half of the Appalachians were accreted to cratonic North America. At the same time, terranes were accreted to the northern margin of the Avalon composite terrane. During the Devonian Acadian Orogeny, terranes were accreted to both sides of the Avalon composite terrane to form the Acadia composite terrane. This was followed in mid Carboniferous times by 1500 km sinistral transcurrent movement of the Acadia composite terrane to its present location. The climatic Hercynian/Alleghanian Orogeny resulted from the collision of Gondwana with North America in the Late Carboniferous and Permian.

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*The Caledonide Orogen, Scandinavia and related areas, eds. D. G. Gee and B. Sturt; Wyllie and Sons, in press.

LITHOGEOCHEMISTRY AS AN INDICATOR OF URANIUM AND TIN MINERALIZATION, SOUTH MOUNTAIN BATHOLITH, NOVA SCOTIA, CANADA*

G. K. Muecke**

and

A. K. Chatterjee

The South Mountain batholith (SMB) is a posttectonic, peraluminous granodiorite-granite complex which outcrops over an area $>10^4$ km^2 of southwestern Nova Scotia. During the past decade the SMB has been the site of increasingly intense mineral exploration which has culminated recently in the discovery of a major tin (East Kemptville, Shell Canada Resources) prospect and a major uranium (Millet Brook, Aquitaine Mining Corporation) prospect, as well as numerous other showings of these metals.

The SMB mainly intruded deformed metawackes and metapelites of the Cambro-Ordovician Meguma Group, but along its northwestern margin it cut metasediments and volcanics ranging in age from Ordovician to Lower Devonian (Emsian). Country rock deformation and metamorphism is attributed to the Acadian Orogeny which, in this region, has been dated at 415-400 Ma. Stratigraphic controls necessitate that the time of intrusion, crystallization, uplift and erosion of the batholith be bracketed between Emsian and Tournaissian times. Recent K/Ar, $^{39}Ar/^{40}Ar$ and Rb/Sr isochron studies assign ages of 372-361 Ma to the various episodes of intrusion in the batholith. Complete solidification and surface exposure of parts of the SMB cannot have been separated by more than a few million years and the rapid unroofing of the batholith during(?) and following its emplacement appears to have strongly influenced the localization of the associated mineralization.

The main mass of the SMB consists of biotite granodiorites intruded by a number of smaller, discrete bodies of biotite-muscovite monzogranites (including porphyry), leucocratic monzogranites, dykes and irregular bodies of aplite and pegmatite. The major and many trace elements of this suite show continuous variation trends from the early to late-stage rocks. From this, McKenzie and Clarke (1975) concluded that the SMB consists of a cogenetic suite with chemical trends controlled by fractional crystallization involving mainly plagioclase and biotite. Muecke and Clarke (1981) concluded from the REE (rare earth elements) and Sr isotope data that fractional crystallization alone cannot account for the trace element geochemistry of the late-stage rocks. They suggested that three processes, namely fractional crystallization, country-rock assimilation, and fluid-phase transfer, all operated during the crystallization history of the SMB. The generation of a fluid phase, possibly enriched in fluorine and/or carbonate ions, is thought to have played a major role in determining geochemical trends during the terminal phases of crystallization. The presence of such a fluid would also have had a profound

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*International Symposium on Geochemistry, Saskatoon, Saskatchewan, May 1982

**Department of Geology, Dalhousie University, Halifax, Nova Scotia influence on the behaviour of such economically important elements as Sn and U, since they can form stable fluoride/carbonate complexes in aqueous solutions.

A **para-intrusive suite,** which consists of biotite leucogranites, argillized and sericitized granites, albitized granites and albitites, as well as various types of greisen, appears to be the product of the interaction of such a fluid phase with residual magma and/or the cogenetic crystalline rocks. Chemical trends in this suite are distinct and clearly diverge from those observed in the cogenetic suite. The Sn-W, Sn-Be, Sn-W-U, W-Mo-U, and U-P-F mineralization in the SMB are usually spatially and genetically associated with the monzogranite and leucocratic monzogranite bodies, and in particular with para-intrusive rocks found within these complexes.

The principal types of U and Sn mineralization so far recognized in the SMB are typified by the following:

i) In the New Ross area uraniferous shear zones occur in granodiorites at Millet Brook, in leuco-monzogranite at Lewis Lake, and at many other localities within the greisen zones. The uraniferous shear zones are characterized by strong wall-rock alteration and autunite-torbernite-pitchblende associations.

ii) The uranium mineralization at Gaspereau Lake and East Dalhousie is restricted to shear zones in leuco-monzogranite. The mineralization is characterized by autunite-meta-autunite-torbernite-pitchblende associated with hydroxylapatite and fluorapatite.

iii) The Sn-W-Cu-Mo mineralization at Davis Lake, Plymouth, and Long Lake is restricted to greisen zones and greisenized granites within descrete bodies(?) of leuco-monzogranite. The dominant polymetallic mineralization at these localities is found mostly as disseminations and as quartz-topaz-cassiterite-sulphide veins. The greisen zones and the veins range in width from hairline fractures to tens of metres.

For most of the plutons in the SMB the U content increases with increasing degree of differentiation, whereas Th steadily decreases in abundance. The mean Th/U ratios change from ≈3 in the granodiorites to ≈0.5 in the leuco-monzogranites. Such a decrease in Th and Th/U (also of REE) is most unusual for a differentiated intrusive suite. The decrease in Th/U with the increase in differentiation is accompanied by strong progressive enrichments in F, Be, Li, Rb, Cs, Ta, Sn, U and depletions in Sr, Ba, REE, Sc, Zr, and Hf. Trace element concentrations in many of the more differentiated rocks fall well within the limits set by Tischendorf (1978) for metallogenetically specialized granites, but Th and REE clearly do not follow his predicted behaviour. In the associated para-intrusive suite the above described elemental correlations often break down and particular elements may show more extreme enrichments (e.g. U, Sn, Li) or depletions (e.g. REE, Th).

The negative correlation between Th and U and the Th depletion with increasing differentiation which we have observed for most of the plutons is, however, not shared by all plutons in the SMB or associated with it. Notable exceptions are the Davis Lake and Plymouth plutons which exhibit a positive correlation between U and Th and elevated Th abundances in the most differentiated rocks and the para-intrusive suite; both bodies are associated with substantial Sn-W mineralization.

From the above discussions it appears that two distinct geochemical trends can be discerned in the plutons which constitute the SMB: i) a Th-depletion (also REE depletion) trend in which increased igneous differentiation leads to low Th and low Th/U, both in the cogenetic and para-intrusive suites; and ii) a Th-enrichment trend in which highly differentiated rocks and para-intrusives are characterized by a concomitant increase in Th and U.

We have analyzed airborne gamma-ray spectrometric maps in an attempt to delimit the location of areas which display the above geochemical trends. In general, the areas of high total count (taken as >10 ur) conform to the major bodies of monzogranite and more highly differentiated rocks (e.g. New Ross complex, Davis Lake pluton). In some cases these more highly radioactive bodies show low Th counts (e.g. New Ross) in accord with the Th-depletion trend observed in ground sampling. In other cases, the high total count value is accompanied by a high Th count (>6 ppm eTh) and confirms the Th-enrichment trend observed in ground samples (e.g. Davis Lake). Superposition of the high total count (>10 ur) and high Th (>6 ppm eTh) areas yields a well-developed zonal distribution of areas with these characteristics near the margins of the batholith. Furthermore, a close correlation exists between such areas and major mineral occurrences (i.e. Plymouth and Davis Lake plutons with Sn prospects; Millet Brook U prospect) which may be of exploration interest. This approach suggests that bodies in the SMB which show the Th-enrichment trend may be more favorable areas for Sn-U mineralization than those showing the Th-depletion trend. Using these criteria a number of other areas in sparsely mapped portions of the SMB stand out as possible exploration targets.

On the ground the best lithogeochemical indicators of Sn-U mineralization in the SMB are the strong enrichments of F, Be, Li, Rb, Cs, Cu, Ta, Sn and U encountered in the associated para-intrusive suite. Furthermore, a preliminary study of REE in fluorites from Sn-U mineralized and apparently barren areas has shown that fluorites in the former have elevated REE concentrations and may prove to be guides to mineralization. Relative REE distributions in all the fluorites closely resemble those observed in the leuco-monzogranites and reflect the close genetic link between the highly differentiated, late crystallized fractions of the batholith and the evolution of the fluid phase which gave rise to the observed mineralization in the SMB.

Vertical profiles of U distributions in the New Ross area show that near-surface samples (<100 m) can be markedly deficient in uranium; other areas (e.g. Davis Lake) do not exhibit such a trend. We suggest that such distribution patterns are the result of the interaction of differentiated granitoid rocks with heated meteoric and/or internally generated fluids. These released and concentrated U through oxidation and complex formation.

The localization of U mineralization along shear zones in the SMB suggests that the rapid unroofing of the batholith following its emplacement produced dilatancy and shear fractures which acted as channelways for mineralizing fluids which were produced as internally generated fluids or by the interaction of the differentiated granitoid rocks with hot meteoric water. Uranium and tin concentrations of economic interest in the SMB are therefore the cumulative result of igneous differentiation processes and a hydrothermal system which acted on the cooling batholith during an episode of rapid uplift.

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MINERAL DEPOSIT STUDIES

CONTRASTING GRANOPHILE (Sn:W:Mo:Cu:U) DEPOSITS OF NOVA SCOTIA

A. E. Chatterjee

A fundamental assumption of economic geology is that of a genetic and geochemical relation between the granophile deposit types and the associated granitoid rocks. The concept of "specialized granites" is commonly used in exploration for such deposits with certain element concentrations being taken as indicators of mineralization or the potential for mineralizaton.

The granophile association of Sn, W, Mo, Cu and U in Nova Scotia occurs in the following four distinct groups: W-Mo-Cu, Mo-Cu, Sn-W-Cu (± Mo), and U-Cu (± Ag ± P). The mineralization is enclosed either in the granitoid rocks (intrabatholithic cf. endocontact) or in the metamorphic country rocks within 5 km from the contact with the granitoid rocks (peribatholithic cf. exocontact). The intrabatholithic mineralization varies in form from a linear type with vein infillings or sheet-like bodies to a columnar type in the metasomatized granitoid rocks. The peribatholithic mineralization occurs as impregnations, as replacement bodies and as net-vein stringers in shear zones in siliceous dolomitic limestone or calcareous pelitic rocks.

W-Mo-Cu association: The W-Mo-Cu mineralization (e.g. Whycocomagh) in Cape Breton Island typically forms a pyrometasomatic aposkarn type of mineralization in the regionally metamorphosed Precambrian siliceous dolomitic limestone of the George River Group.

The skarnization and metallisation was a two stage process. The first stage produced largely an anhydrous mineral assemblage characterized by granoblastic, Ti-rich andradite (Ad_{60}-Gr_{37}), clinopyroxene of the diopside-hedenbergite series (Di_{95}-Hd_4 to Di_{85}-Hd_{14}), forsterite, ilvaite, spinel and sphene. During the second stage (fluorothermal) the earlier formed minerals were corroded and replaced by talc-antigorite-tremolite assemblage together with an assortment of accessory minerals typified by fluorite, fluorapatite, fluorphlogopite and chondrodite.

Geochemically, the anhydrous skarns are of uniform character and mass balance calculations indicate that a large introduction of Si, Ti, Fe, K and Al has taken place in the siliceous dolomitic limestone during skarnization. During the fluorothermal stage, though the aposkarns do not show significant changes in the bulk chemistry, the level of concentration and the ratios of various metallogenic elements show marked changes. These changes include the introduction of W, F, Cu, Mo, Sn, Co, Ni and Ag together with other trace elements.

The mineralizing solutions were internally generated fluids, derived from cooling of the I-type, polyphase granitoid complexes whose trace element concentrations do not fall within the limits of the metallogenetically specialized granites. However, these are characterized by a large percentage dissimilarity in trace element concentrations. The calculated values are W 68%, Mo 92%, Cu 74%, F 48% and H 39%. In comparison, the calculated values for barren granitoid complexes of Cape Breton Island are W 6%, Mo 4%, Cu 2%, F 10% and H 16%.

Cu-Mo association: The Cu-Mo association occurs in intramagmatic typically I-type polyphase granitoid complexes (e.g. Coxheath, Gillis Mountain). The mineralization is largely confined to shear zones and also in vein swarms and stock work. Petrologically, the complexes are represented by gabbro, diorites, monzodiorites, hornblende granodiorites, granites and minor quartz porphyry.

Geochemically the hydrothermally altered rocks are extremely heterogeneous and the variation diagrams are complex. However, it appears that the gabbro together with diorites and granite form a single magmatic series with a well defined geochemical trend. The other igneous suite with which the mineralization is spatially associated, is characterized by geochemically specialized K-rich quartz diorites, Na-rich granodiorites and Na-rich granites.

Microprobe studies of alteration minerals indicate that hydrothermal pyroxene, amphibole, and biotites are magnesium rich and titanium poor when compared to magmatic silicates from the same, or similar rock types. The distribution and composition of chlorite, sericite and epidote are not always related spatially to the mineralization. The alteration-mineralization zonation is characterized by increasing Mg/Mg+Fe ratios in biotite, amphibole and pyroxene towards the mineralized veins.

In comparison to the barren diorites and granites, the mineralized plutonic complex, at least at Coxheath, is specialized in B, S, Co, Ni, Cr, Cu, and Zn. Also, when compared to the metallogenetically specialized Devono-Carboniferous granites of southern Nova Scotia and Hercynian Europe, the metallogenetic specialization of ferrous metals in the granitoid complexes hosting Cu-Mo mineralization is clearly a departure from the predicted behaviour of these elements in the grainitoid complexes.

Sn-W-Cu-(±Mo) association: This type of association typically occurs in an endo-contact environment forming various types of greisens (e.g. East Kemptville, Long Lake, Wedgeport) and also as polymetallic veins in an exo-contact environment (e.g. Plymouth).

The mineralization is typically represented by cassiterite-wolframite-chaloopyrite association together with large assortment of accessory sulphide and oxide minerals which include sphalerite, bornite, arsenopyrite, tetrahedrite, ilmenite, pyrite, pyrrhotite, and hematite in a gangue mineral assemblage of white mica, albite, topaz, beryl, fluorite, fluorapatite, triplite, cryolite, phenakite and bertrandite.

The mineralization is spatially and genetically related to highly differentiated Di>90 2-mica leucogranite complexes of Devono-Carboniferous age. The granitoid complexes include biotite granite, sericitized granite, albitized granite, and various types of greisens. The typomorphic features of the constituent minerals of the granitoid rocks include Co/Ni ratio of pyrite, compositional variation of plagioclase feldspars, lack of equilibrium between coexisting micas, and crystallochemical typomorphism of cassiterites and sphalerites. The trace element concentrations in the 2-mica leucogranites fall well within the limit set for the metallogenetically specialized granites associated with the granophile deposits of Hercynian Europe.

U-Cu (± Ag ± P) association: The U-Cu (± Ag ± P) association (e.g. Millet Brook, East Dalhousie, Gaspereau Lake) typically occurs in closely spaced en echelon pods and lenses confined to shear and fracture zones in the granitoid rocks of the South Mountain batholith. The host rocks range in composition from granodiorite to leuco-adamellites.

The uraniferous shear zones are characterized by strong wallrock alteration and mineralogical changes include albitization, muscovitization, biotitization, chloritization, K-fedspathization and carbonitization. The ore mineralogy is dominated by pitchblende, torbernite, autunite and minor amounts of chalcopyrite, bornite, galena, covellite, chalcocite, sphalerite, and wolframite. The associated gangue minerals are quartz, feldspars, micas, illite-smectites, fluorapatite, andalusite, tourmaline, chlorites, carbonates, pyrite, garnet, Mn-oxides, and anatase.

It is suggested that the formation of uranium mineralization was related to late stages of felsic magmatism and the mineralizing solutions were initially internally generated fluids which evolved through borothermal and carbothermal stages as end-members in a spectrum of deposits formed by the action of thermal fluids.

PROGRESS REPORT: GEOCHEMISTRY*

P. J. Rogers

Work effectively commenced June 1, 1982 with the arrival of P. J. Rogers as geochemist and M. A. MacDonald as assistant geochemist. Fieldwork started June 7, 1982 in Cape Breton Island and finished September 10, 1982.

The aims of the program are to determine the regional variation and the geochemical behaviour of stream sediments in Nova Scotia as an aid to exploration and environmental studies. The program will complete the stream sediment sampling of northern Nova Scotia and Cape Breton Island (Fig. 1) in 1983. Additionally, the existing analytical data from previous surveys will be adjusted to a common base to be compatible with the new

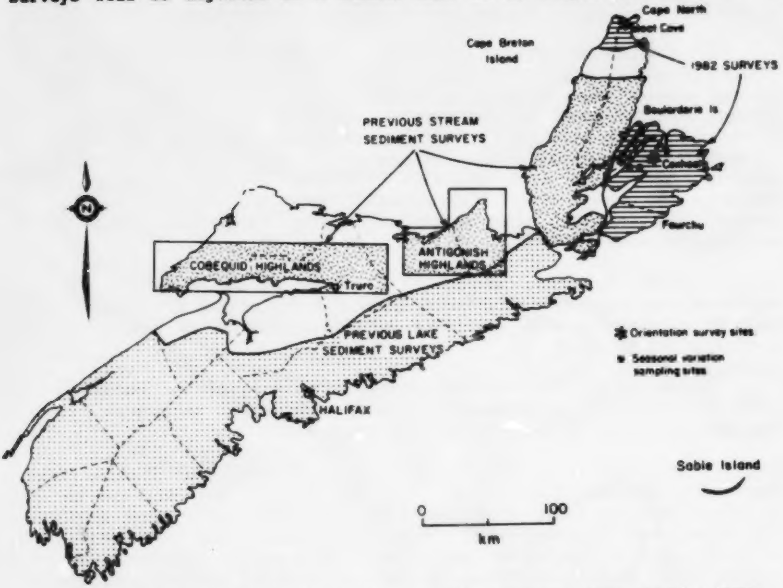
Cape North
Cape Breton Island
1982 SURVEYS
Boularderie Is
PREVIOUS STREAM SEDIMENT SURVEYS
Fourchu
N
COBEQUID HIGHLANDS
ANTIGONISH HIGHLANDS
Truro
PREVIOUS LAKE SEDIMENT SURVEYS
HALIFAX
Orientation survey sites
Seasonal variation sampling sites
Sable Island
0
100
km

Figure 1. Extent of geochemical survey's coverage, Nova Scotia (post 1970).

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*Contribution to Canada-Nova Scotia Co-operative Mineral Program 1981-84. Project carried by Geological Survey of Canada and Nova Scotia Department of Mines and Energy.

data collected. One of the long term aims is the production of a geochemical atlas for Nova Scotia integrating geochemical data from stream sediments, tills, lake sediments and rocks with the geophysical and geological information data bases extant.

The field sampling was completed mostly using road access and conducted by M. A. MacDonald assisted by six students. A total of 1345 samples were collected at a linear spacing of about 2 km. Wherever possible most first, second and third order streams were sampled. During the summer a total area of approximately 4500 km^2 in eastern and northern Cape Breton Island were sampled, a density of about 1 per 3.4 km^2.

Most samples were hand sieved in the field to pass a 1 mm nylon mesh screen and the sediment collected in a plastic pan taking care to avoid any fines loss. All information was coded on standard Geological Survey of Canada cards for subsequent computer processing.

The areas covered included the Cape North, Boularderie and Fourchu regions (Fig. 1). Widely differing drainage, physiography and geology between these regions was noted and with this in mind, orientation surveys were performed at Meat Cove (Zn skarn type) and Coxheath (porphyry Cu type). Stream sediments were collected at 150 300 m and 600 m spacings to estimate geochemical dispersion patterns, the effects of varied sample spacings, the use of different size fractions, and analytical extraction methods. No heavy mineral concentrates were collected although it is intended to test their applicability by heavy liquid separations of the orientation study samples.

Bulk standards of about 10 kg of -1 mm mesh material were collected from representative rock types and environments. These will be used in conjunction with duplicate and split samples to test analytical precision and accuracy.

During the summer, two sites were selected for monitoring of seasonal variations in elemental values in the stream sediments. Routine samples are collected every month from these sites (Fig. 1).

Most of the samples will be submitted for routine atomic absorption analysis for Cu, Pb, Zn, Ag, Co, Ni, Fe, Mn, and Mo with additional tests for Hg, U, and As. The applicability of other analytical techniques such as inductively coupled plasma-atomic emission spectrometry (ICP-AES) will be tested on the orientation samples. Analysis of water samples was not included this year due to logistic constraints, but will probably be included as an adjunct to the stream sediment sampling next year.

After verification of the analyses the data will probably be released as a series of single element maps at the scale of 1:250 000. These maps will be portrayed on a geological base and include basic statistics together with histogram and cumulative frequency plots.

The distribution of higher values will be highlighted using half-tone scaled plots on a black and white base. These data will then be combined with previous information and computer processed to produce colour 1:1 000 000 geochemical environment maps for Nova Scotia.

The 1983 field program will concentrate on stream sediment sampling in mainland northen Nova Scotia in the Cobequid and Antigonish highlands and Truro Minas Basin areas. Some sampling of lakes in the Fourchu region will be used to correlate stream and lake sediment geochemistry within the Province.

SYDNEY BASIN PROJECT

P. S. Giles

INTRODUCTION

Geological studies of Carboniferous rocks in the Sydney Basin, Cape Breton Island, Nova Scotia, were initiated in May 1982 as part of the Canada-Nova Scotia Co-operative Mineral Program (CNSCMP). Staff of the Nova Scotia Department of Mines and Energy undertook stratigraphic and structural studies in that area stretching from Sydney Harbour northwesterly to the Great Bras d'Or (Figs. 1 and 2) and southwesterly to include the Scotch Lake-Frenchvale extension of the Sydney Harbour Syncline, as well as Boularderie Island.

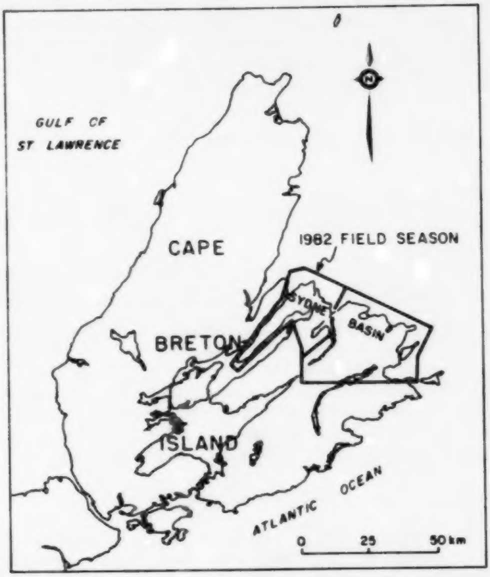

Figure 1. Sydney Basin Project, location map.

Concurrently, Dr. Brian Rust of the University of Ottawa and Dr. Martin Gibling of Dalhousie University undertook detailed sedimentological analysis of the lower part of the Morien Group, studying well-exposed coastal sections throughout the Sydney Basin. Selected sections of the lower Morien were studied in detail by Sean Dilles of the University of Ottawa in work leading to a M.Sc. degree. Similar detailed and comprehensive sedimentological analysis of the upper part of the Morien Group was continued by Guy Masson as part of his doctoral dissertation in progress at the University of Ottawa. This sedimentological research, described by

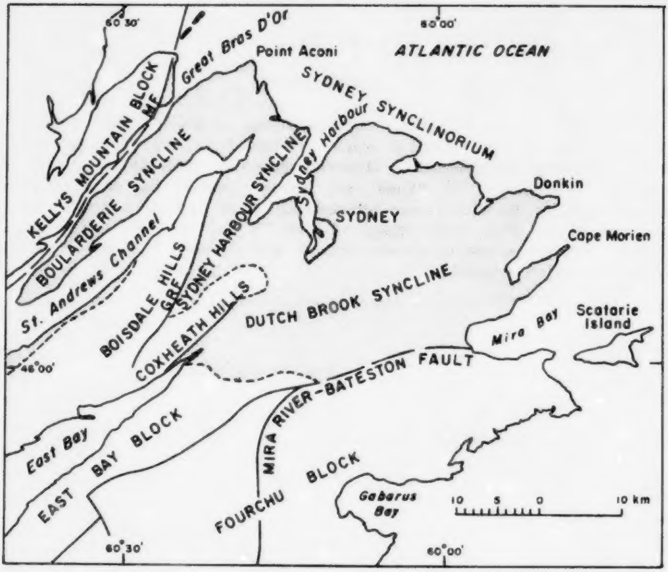
60°30'
60°00'
ATLANTIC OCEAN
Point Aconi
Great Bras D'Or
KELLYS MOUNTAIN BLOCK
MF
BOULARDERIE SYNCLINE
St. Andrews Channel
BOISDALE HILLS
GRF
SYDNEY HARBOUR SYNCLINE
Sydney Harbour
SYDNEY SYNCLINORIUM
SYDNEY
Donkin
Cape Morien
COXHEATH HILLS
DUTCH BROOK SYNCLINE
Mira Bay
Scatarie Island
46°00'
MIRA RIVER-BATESTON FAULT
East Bay
EAST BAY BLOCK
FOURCHU BLOCK
Gabarus Bay
10 5 0 10 km
60°30'
60°00'

Figure 2. General structural features of the Sydney Synclinorium.

Dilles and Rust (this volume) and Rust et al. (this volume) permits significant advances in the geological understanding of the Morien Group. On a larger scale, the results of the 1982 field program permit a broader understanding of the sedimentary and structural history of the onshore Sydney Basin and its total Carboniferous fill. This brief report summarizes the observations made to date, and will be followed by more detailed reports subsequent to the second (and final) year of the project.

GEOLOGICAL SETTING

The Sydney Synclinorium (Keppie, 1982) is bounded on the south by pre-Carboniferous rocks of the East Bay and Fourchu Blocks, and on the northwest by the Kellys Mountain Block. Both margins are major fault boundaries. The Synclinorium comprises three major synclines with intervening arches, formed by pre-Carboniferous rocks of the Coxheath and Boisdale Hills (Fig. 2). A pronounced northeasterly trend is noted for most major structures.

Data generated during this study indicate that the broad structural configuration of the Sydney "Basin" was achieved in Viséan time or slightly earlier. Post-Carboniferous fault movements have accentuated the major boundaries, but at present limit a formerly more extensive basin of similar configuration.

STRATIGRAPHY AND SEDIMENTOLOGY

In ascending stratigraphic order, the Carboniferous succession of the Sydney Basin comprises the Grantmire Formation, the Windsor Group, the Point Edward and Cape Dauphin Formations and the Morien Group. These rock units range collectively in age from pre-Middle Viséan to Late Westphalian. Their interrelationships are shown schematically in Figures 3 and 4, and are described in subsequent paragraphs.

Grantmire Formation

The term Grantmire was first applied by Bell and Goranson (1938a, b, and c) to a conglomeratic sequence flanking the Coxheath Hills. The Grantmire was given member status by these authors, who believed that it represented the lowest rock unit of the Windsor Group. Weeks (1954) raised the Grantmire to formational status and applied the name to all Windsor conglomeratic sequences forming the base of the Windsor Group. Boehner (1981, p. 156) showed that "Grantmire" conglomerate occurs as tongues and wedges at many stratigraphic horizons throughout the Windsor Group, and

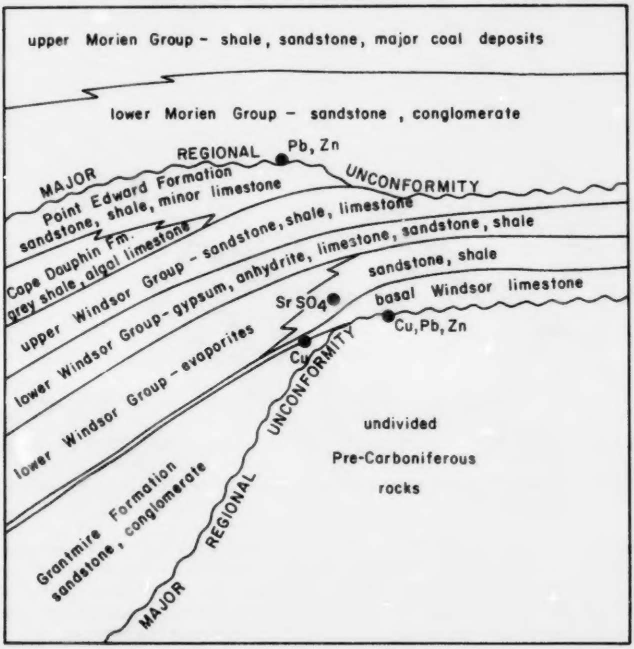
upper Morien Group - shale, sandstone, major coal deposits
lower Morien Group - sandstone, conglomerate
MAJOR REGIONAL UNCONFORMITY
Pb, Zn
Point Edward Formation
sandstone, shale, minor limestone
Cape Dauphin Fm.
grey shale, algal limestone
upper Windsor Group - sandstone, shale, limestone
lower Windsor Group - gypsum, anhydrite, limestone, sandstone, shale
sandstone, shale
Sr SO4
basal Windsor limestone
Cu, Pb, Zn
Cu
lower Windsor Group - evaporites
Grantmire Formation
sandstone, conglomerate
MAJOR REGIONAL UNCONFORMITY
undivided
Pre-Carboniferous
rocks

Figure 3. Regional stratigraphic relationships, Carboniferous rocks of the Sydney Basin. No vertical scale implied.

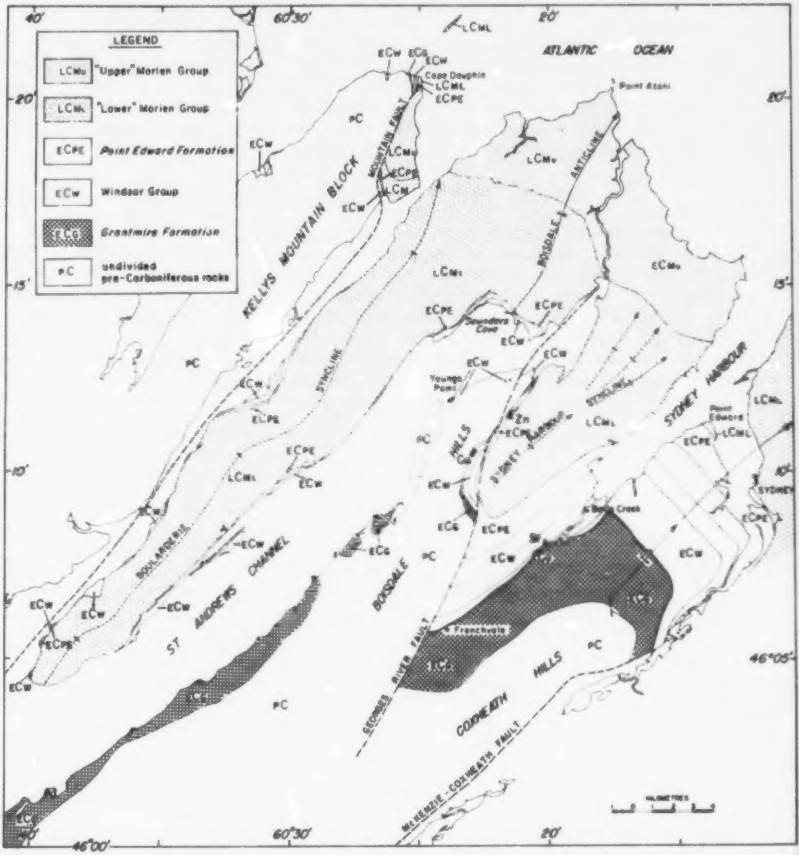
LEGEND
LCMu "Upper" Morien Group
LCML "Lower" Morien Group
ECPE Point Edward Formation
ECW Windsor Group
ECG Grantmire Formation
PC undivided pre-Carboniferous rocks
ATLANTIC OCEAN
Cape Dauphin
Point Aconi
KELLYS MOUNTAIN BLOCK
MOUNTAIN FAULT
BOISDALE ANTICLINE
SYNCLINE
Saunders Cove
Youngs Point
Zn
SYDNEY HARBOUR
Point Edward
SYDNEY
BOULARDERIE
ST ANDREWS CHANNEL
BOISDALE HILLS
Frenchvale
GEORGES RIVER FAULT
COXHEATH HILLS
MCKENZIE - COXHEATH FAULT
KILOMETRES
40'
60°30'
20'
46°00'
46°05'
20'
15'
10'

Figure 4. Geological map of the northwestern part of the onshore Sydney Basin.

could not be pratically applied to a mappable rock unit. He suggested that the term be abandoned in the Loch Lomond area of southeastern Cape Breton Island. The present mapping, which includes the type area of the Grantmire of Bell and Goranson, suggests that the term can be usefully retained with appropriate redefinition as indicated in subsequent paragraphs.

The writer recommends that the term Grantmire be applied to that succession of brick-red to maroon conglomerate, sandstone and shale extending from the major pre-Carboniferous unconformity to the base of the Macumber (or Gays River) Formation of the Windsor Group. This definition excludes the Grantmire Formation from the Windsor Group following the recommendation of the present author for the definition of the base of the Windsor (Giles, 1981) and represents a significant departure from the original definition of Bell and Goranson (1938a, b, and c) and the modified Grantmire of Weeks (1954).

No attempt has been made here to subdivide this Grantmire which is up to 700 m thick, nor to study its sedimentological history in detail. Its spatial distribution, coarse and poorly sorted nature, and pervasive red colour suggest that it represents the deposits of a series of alluvial fans with possible fluviatile influence in its upper parts.

Windsor Group

In this report, the lower and upper boundaries of the Windsor Group are placed respectively at the base of the Macumber Formation or laterally equivalent marine rocks, and at the top of the E_1 limestone member, as recommended by Giles (1981) and Giles and Boehner (1982).

The most comprehensive descriptions of Windsor Group strata are presented in Bell (1958), and include summaries of sections measured on the shores of the Point Edward peninsula and at Saunders Cove at the northwesterly end of St. Andrews Channel (Fig. 4). Beds assigned here to the Windsor Group extend, in the Point Edward section, from the base of the so-called Kellys Hill limestone to the top of the Dixon Point limestone (Bell, 1958, p. 155-157) for a reported total thickness of 817 m. Tentative correlation of these limestone members with the Macumber Formation and the E_1 limestone member respectively, suggests that this thickness is representative for the total Windsor Group as here defined.

Basal Windsor limestones have been mapped from the southwesterly apex of the northwestern arm of Sydney Harbour, southwesterly through the Frenchvale area to the Georges River Fault (Fig. 4). Excellent exposures can be seen in abandoned quarries northeast of Frenchvale, and in roadside excavations on the Trans-Canada Highway at Kellys Hill near Balls Creek. The limestones are typically peloidal or intraclastic and very sparsely fossiliferous. Distinctive lamination typical of the Macumber Formation is locally present, but more massive beds are most common.

Mottled algal limestones typical of the Gays River Formation (Giles et al., 1979) occur at several localities peripheral to the northeasterly extension of the Boisdale Hills (Fig. 4), when they lie unconformably on pre-Carboniferous rocks. These limestones are best exposed at Youngs Point and in the bed of the Georges River where local concentrations of shelly fossils have been noted.

The development of algal limestones of the Gays River type is believed to occur updip from typical Macumber facies limestones at the base of the Windsor (Giles et al., 1979; Giles, 1981) and clearly implies that the Boisdale Hills existed as a positive topographic feature during the time of Windsor sedimentation.

On the northern flanks of the Kellys Mountain Block (Fig. 4) and beyond the limits of the present map area, similar algal limestones of Gays River Formation type occur on the coast as a thin discontinuous veneer lying on pre-Carboniferous rocks. Thus, the Kellys Mountain Block, like the Boisdale Hills, appears to have had positive topographic expression during Windsor sedimentation.

Detailed study of the Windsor Group will continue during the second year of the project. Upper Windsor strata exposed on both margins of the Boularderie Syncline (Fig. 4) can be compared closely with Upper Windsor strata elsewhere in Nova Scotia and correlated on a member-for-member basis (see, for example, Giles and Boehner, 1982). It is gratifying to report rugose coral faunas from the E_1 limestone at several localities, corroborating the correlation of the E_1 and Kennetcook Limestone Members postulated earlier by the writer (Giles, 1981).

In general terms, the Windsor Group appears, in the present map area, to be characterised by an abundance of relatively coarse grained terrigenous detritus with intercalated marine limestones and dolostones. Evaporitic lithologies are generally subordinate, but may be more common than indicated by the sparse outcrop data. Presently available subsurface data are not adequate to confirm this hypothesis.

Point Edward (and Cape Dauphin) Formation(s)

Named for exposures on the Point Edward peninsula by Hyde (1913), the Point Edward Formation comprises an estimated 213 m of red and green shale with minor sandstone, and several intercalated beds of limestone of presumed fresh-water origin. Hyde (1913) recognized the lateral extension of the Formation from its type area, westerly through the Sydney Harbour Syncline, and noted its reappearance on the southern flank of the Boularderie Syncline (Hyde, 1913, p. 393). The present study confirms the work of Hyde (1913), and extends the Formation's distribution to include the northern limb of the Boularderie Syncline. Furthermore, sections measured on the northern shore of St. Andrews Channel and at Cape Dauphin (Fig. 5), clearly support correlation of the Cape Dauphin Formation of Bell and Goranson (1938c) with the Point Edward Formation. Because these two Formations appear to be completely transitional one with another, and because the Cape Dauphin Formation is known only from its type locality, the writer recommends that the name Cape Dauphin Formation be abandoned.

Lithologically, the Point Edward Formation is dominated by shales and silty shales, predominantly grey at Cape Dauphin, but mainly red in colour in the Point Edward section. Stromatolitic limestones comprise a minor but distinctive part of the succession. It should be noted here that the lowermost 140 m of the type section at Point Edward is concealed. The section at Cape Dauphin, 78 m in thickness, may correlate mainly with grey(?) strata hidden in that interval. Figure 5 clearly shows the lateral variation in colour of the shales in the lowermost Point Edward Formation, lending support to this suggestion.

No angular discordance can be detected between beds of the uppermost Windsor and the Point Edward Formation. At Cape Dauphin, no break in sedimentation is apparent, and the basal beds of the Point Edward comprise grey shales of probable shallow lacustrine origin. West of the mouth of Black Brook (Fig. 5) limestone clasts in the basal red siltstone of the Point Edward attest to some erosion of the underlying E_1 limestone, and at

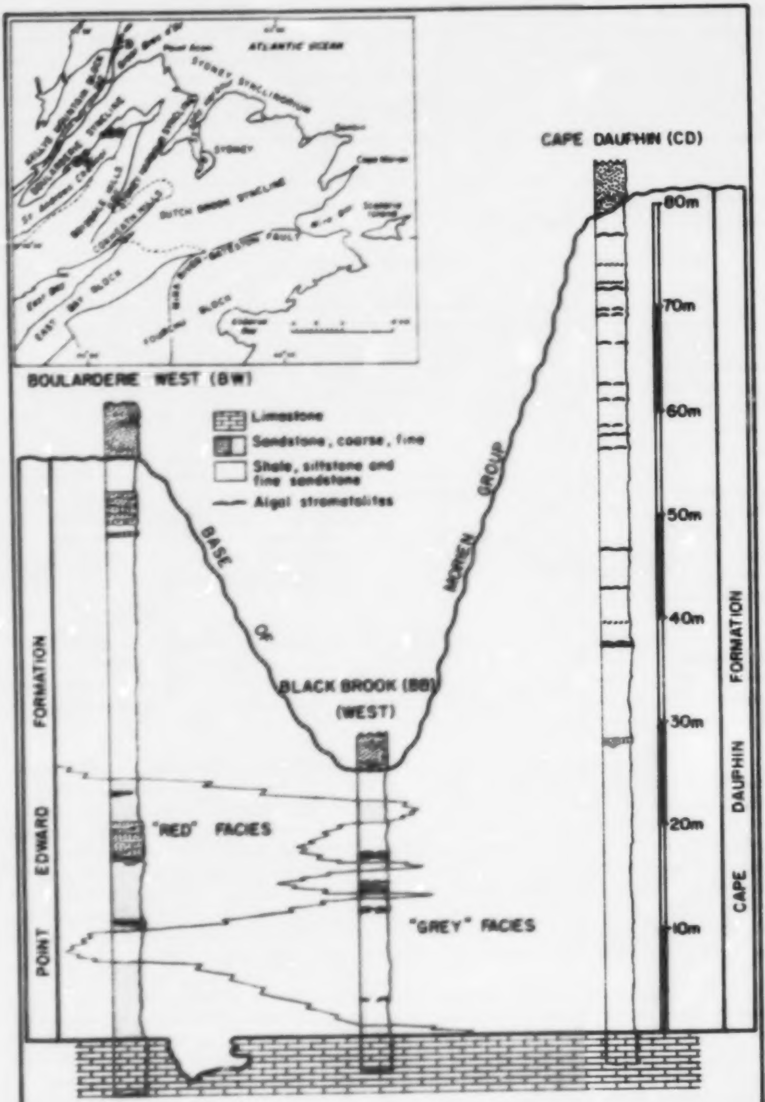
ATLANTIC OCEAN
SYDNEY
SYDNEY SYNCLINORIUM
DUTCH BROOK SYNCLINE
EAST BAY BLOCK
FAULT
BOULARDERIE WEST (BW)
Limestone
Sandstone, coarse, fine
Shale, siltstone and fine sandstone
Algal stromatolites
BASE OF MORIEN GROUP
CAPE DAUPHIN (CD)
BLACK BROOK (BB) (WEST)
80m
70m
60m
50m
40m
30m
20m
10m
"RED" FACIES
"GREY" FACIES
POINT EDWARD FORMATION
CAPE DAUPHIN FORMATION

Figure 5. Sections of the Point Edward Formation measured at Boularderie West, Black Brook and Cape Dauphin.

Boularderie West, major corrosion of the underlying E_1 limestone appears to predate deposition of the Point Edward shales. This locality was cited by Hyde (1913, p. 393-394) as evidence for an "erosional unconformity" between the Windsor Group and the Point Edward Formation. It appears that in areas peripheral to major upland blocks, underlying Windsor strata were subaerially exposed and subjected to both erosion and corrosion, whereas sedimentation continued uninterrupted in more distal areas.

The upper contact of the Point Edward Formation, in contrast, is a highly irregular surface and a major regional unconformity which defines the base of the Morien Group.

Morien Group

Detailed study of the Morien Group is in progress by Drs. Brian Rust and Martin Gibling and graduate students Guy Masson and Sean Dilles. Preliminary results are presented elsewhere in this volume. The writer's observations corroborate the views expressed by these authors. A regional perspective of the Morien is presented here, in order to allow a broad understanding of the sedimentary and structural history of the Sydney Basin.

In the onshore parts of the basin, rocks of the Morien Group are of Westphalian C and D age, extending into the Stephanian at Point Aconi (Hacquebard, 1983) and in the offshore areas. Hacquebard (1983, p. 72) excluded strata of Stephanian age from the Morien Group. Because Stephanian rocks have such extremely limited vertical and lateral distribution onshore, they are here included within the upper subdivision of the Morien Group (see subsequent paragraphs).

The base of the Morien Group is exposed at numerous localities on both limbs of the Boularderie Syncline, at Cape Dauphin, at Leitches Creek and on the shores of Sydney Harbour. The basal Morien strata range from cobble conglomerate (Cape Dauphin) to pebbly sandstone and sandstone at other localities.

Independent of the three fossil floral assemblage zones recognized by Bell and Goranson (1938a, b, and c), two major lithostratigraphic subdivisions of the Morien Group can be recognized throughout the Basin. The lower subdivision is dominated by grey sandstone, medium to thickly bedded, with minor, discontinuous units of grey shale and very minor coal near the top. Trough stratification at a medium to large scale is characteristic. Thin, lensoidal beds of conglomerate occur throughout this succession, and are usually but not always concentrated in its lower parts. The thickness of this lower subdivision is estimated to exceed 500 m, but the lack of marker horizons makes this figure highly uncertain.

The upper subdivision of the Morien Group exceeds 600 m in thickness in the onshore areas and may be much thicker. The base is marked by the first appearance in the succession of thick, laterally persistent shales, which are typically grey in colour. The upper boundary is presently undefined. The characteristic rock types include grey shales and silty shales with associated coal seams, several of which are of major economic importance. Grey sandstones are interspersed throughout the succession (Fig. 6). Lateral persistence of the sandstone bodies is variable.

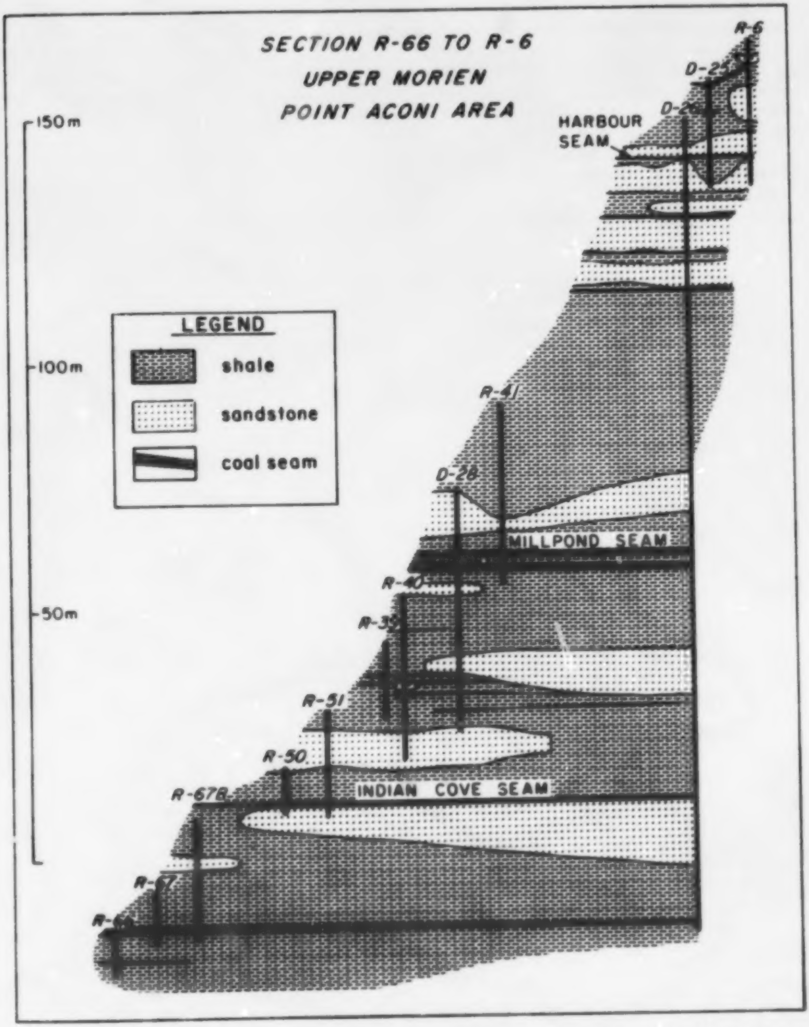
SECTION R-66 TO R-6
UPPER MORIEN
POINT ACONI AREA
150m
100m
50m
LEGEND
shale
sandstone
coal seam
R-6
D-25
D-26
HARBOUR SEAM
R-41
D-28
MILLPOND SEAM
R-40
R-39
R-51
R-50
INDIAN COVE SEAM
R-67B
R-67
R-66

Figure 6. Restored stratigraphic cross-section of upper Morien Group strata in the Point Aconi area; data from unpublished report for NOVACO by David S. Robertson and Associates, 1975.

They range in thickness from 1 m to 10 m and may exceed that thickness where stacking of sandstone bodies occurs.

A variety of sedimentary structures can be seen in sandstones of the Morien Group, and in associated strata. The reader is referred to the work of Rust et al. (this volume) for more detailed description.

Figure 7 shows the dispersal patterns for Morien sediments as indicated by trough long axes recorded throughout the 1982 map area.

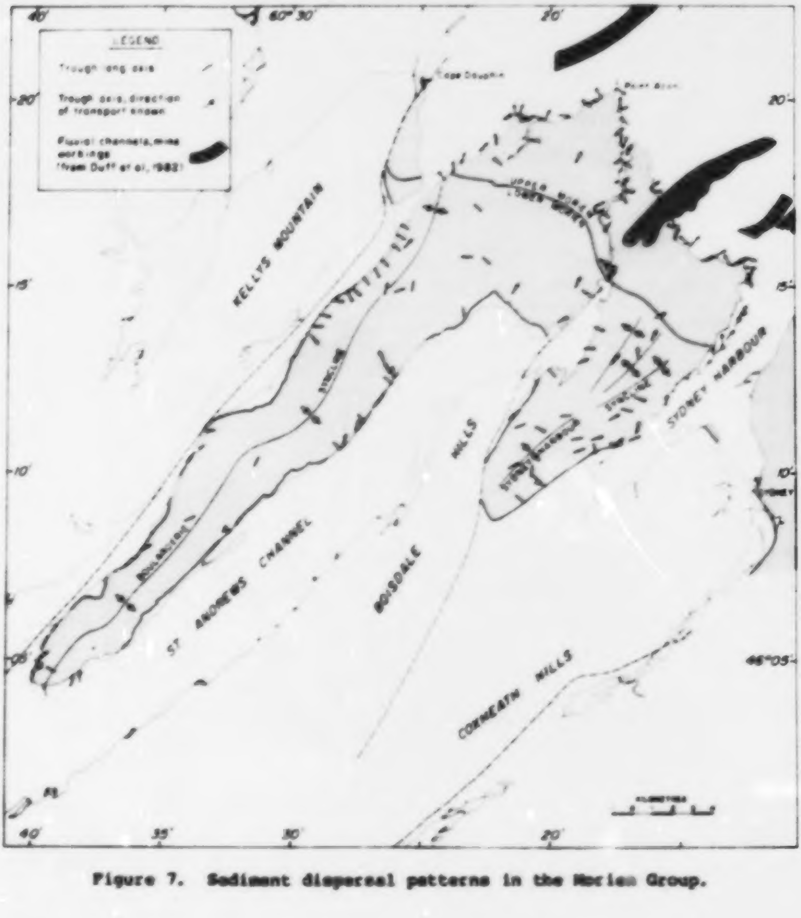
LEGEND
Trough long axis
Trough axis, direction of transport known
Fluvial channels, mine workings (from Duff et al, 1982)
40'
60°30'
20'
Cape Dauphin
Point Aconi
KELLYS MOUNTAIN
UPPER MINES
LOWER MINES
SYNCLINE
SYNCLINE
SYDNEY HARBOUR
SYDNEY
HILLS
BOISDALE
ST ANDREWS CHANNEL
COXHEATH HILLS
15'
10'
46°05'
KILOMETRES
35'
30'

Figure 7. Sediment dispersal patterns in the Morien Group.

Trough axes show clearly that the Boularderie Syncline was also a depositional trough, fed from both the north and south, but with a major component of longitudinal transport towards the northeast. Fanning of trough axes around the northeasterly extremities of the Boisdale Hills indicates a control by this pre-Carboniferous block of regional paleocurrent patterns during deposition of the lower subdivision of the Morien. Transport northerly and northeasterly off the Coxheath Hills, suggests that the Sydney Harbour Syncline was also a depositional feature. The pronounced northeasterly dispersal pattern documented in this study corroborates the regional trend shown by Duff et al. (1982). In addition, however, the present results show more local influence of dispersal patterns by small upland blocks.

Disperal patterns are reasonably consistent within small areas in the lower Morien but are much more diverse within the upper subdivision (Fig. 7). This change reflects the upwards change from a braided stream depositional regime to a meandering fluviatile system, and is consistent with the appearance in the upper subdivision of significant proportions of shales and silty shales representing overbank deposits within a broad floodplain (see report by Rust et al., this volume).

Bell and Goranson (1938a) postulated that the strata of the lowermost Morien were diachronous, with younger strata overstepping older beds in the northern and northwestern parts of the Sydney Basin. This interpretation, based on macrofloral zones, has been supported by Hacquebard (1983) who cites work by Barss and Hacquebard (1967) using plant and spore fossils as corroborating evidence. Present mapping suggests the possibility that this interpretation should be critically re-examined. Specifically, lowermost Morien strata on both the northern and southern limbs of the Boularderie Syncline are lithologically indistinguishable and can be traced physically around the nose of the Syncline. M. S. Barss at the Atlantic Geoscience Centre has kindly agreed to assess the palynomorph assemblages from critical samples collected at Cape Dauphin and on both limbs of the Boularderie Syncline, in order to further test Bell and Goranson's (1938a) original hypothesis in that area.

There is no doubt, however, that the first deposition of major overbank shales (with associated coal seams) in the Morien succession, occurred earlier in the southeastern parts of the Sydney Basin (Dilles and Rust, this volume) than in the present map area. Thus, the boundary between the lower and upper subdivisions of the Morien used in the present mapping is diachronous on a regional scale. This observation suggests that potential coal resources might exist within the submarine portions of the northwestern part of the Sydney Basin, in strata which are laterally equivalent to the sand dominated lower Morien rocks in the 1983 map area. The economic potential of these possible coal resources may be limited by many factors including their depth of burial.

STRUCTURAL SETTING

Folds

On a regional scale, outcrop patterns define two major synclines within the map area, termed the Boularderie and Sydney Harbour Synclines by Bell and Goranson (1938a, b, c). A broad arch reflecting the northeasterly extension of the Boisdale Hills, separates these Synclines. A similar arch is apparent over the basinward continuation of the Coxheath Hills. The former arch was termed the Boisdale Anticline by previous workers, and apparently extends into the offshore area of the Sydney Basin (Hacquebard, 1983) where the same name is applied. Because mapping is not yet complete, it is uncertain whether the arch over the Coxheath Hills extension is equivalent to the Bridgeport Anticline of Bell and Goranson (1938b), or represents a larger structure, not yet formally named.

All major folds are best defined by attitudes and outcrop patterns of the older Carboniferous strata. Definition becomes very subjective in upper Morien strata to the northeastwards where smaller scale folds are apparent, and where beds are very gently dipping. The difficulty in extending major fold axial traces to the northeast suggests that youngest Carboniferous strata represent the last stages of filling of a pre-existing topography, and that major folds and arches no longer dominated the structural setting. The offshore extension of the Boisdale Anticline (Hacquebard, 1983) may present an exception to this general observation.

Faults

Most major faults within the Sydney Basin are aligned approximately parallel to the regional northeasterly structural trend. They include the Mountain Fault on the northwestern limits of the map area, and its postulated extension through the Great Bras d'Or channel; the Georges River Fault which forms the easterly and southeasterly limit of the Boidale Hills (Figs. 2 and 4); and the McKenzie-Coxheath Fault, forming the southern boundary of the Coxheath Hills (Figs. 2 and 4). The Mira River-Bateston Fault which limits the Sydney Basin to the south (Fig. 2) is highly arcuate in trace. It lies beyond the limits of the 1982 map area and is not considered here.

Each of the above faults cuts lower Morien strata. The Mountain Fault also affects upper Morien strata. The Georges River and McKenzie-Coxheath Faults are not known to affect upper Morien strata, suggesting that their latest movements predate deposition of the upper Morien.

All pre-Morien strata are cut by the major northeasterly trending faults. In areas proximal to the fault traces, beds are typically steeply dipping, flattening rapidly to dips of 10 to 15 degrees away from the fault trace. With the possible exception of the Georges River Fault (Fig. 4) few data exist to show conclusively the movement history of these faults.

Evidence for significant strike-slip movement on the Georges River Fault is the termination and apparent offset of the Grantmire Formation outcrop belts flanking the Boisdale and Coxheath Hills (Fig. 4). Dextral movement of at least 18 km would explain the present outcrop geometry, and greater lateral displacement is possible. Inability to trace the fault through upper Morien strata to the northeast suggests that the strike-slip movement was pre-Morien in age. However, steep dips of lower Morien beds adjacent to the Georges River Fault attest to post-Morien vertical movements, illustrating the complexity of fault-movement history within the area.

ECONOMIC CONSIDERATIONS

Within the Sydney Basin, coal is the major resource. The work of Hacquebard (1983) summarizes the geological and economic evaluation of the coal resources. Hacquebard (1983) reported total 'demonstrated' coal resouces, including both on- and offshore areas within the Sydney Basin, at 1.6×10^9 t.

Base metal exploration within the Basin has been concentrated in the Sydney Harbour Syncline, particularly on its southeastern limb where copper mineralization has been documented at the Grantmire-Windsor contact, but also in the core of the Syncline where lower Morien strata have been drilled extensively for lead and zinc. Diamond-drill cores are unfortunately no longer available for examination. However, from assay values reported in assessment reports on file with this Department, it appears that the potential for sandstone-hosted Pb-Zn deposits within lower Morien strata of the Sydney Basin should not be discounted. During the second year of the project, a more detailed assessment of this potential will be attempted.

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THE SEDIMENTOLOGY OF THE LOWER MORIEN GROUP NEAR PORT MORIEN, NOVA SCOTIA*

S. Dilles** and B. R. Rust**

ABSTRACT

The lower Morien Group (Westphalian C age) is an alluvial succession comprising two facies associations: a sandstone facies association and an alternating facies association. The sandstone facies association occurs in the lower part of the succession and outcrops in the southern part of the study area. It is dominated by trough cross-stratified sandstone in fining-upward sequences with erosional bases; coal seams and mudstone units are rare. It is attributed to deposition on a distal sandy braidplain.

The alternating facies association is characterized by an alternation of fining-upward sandstone and coal-bearing mudstone sequences, the latter comprising one half to one third of the succession. The association is attributed to deposition by a meandering alluvial system, in which compaction of extensive muddy floodplain deposits maintained high water tables, and permitted accumulation of thick peat units.

INTRODUCTION

The Pennsylvanian Morien Group in the Sydney Basin of Cape Breton Island, Nova Scotia was divided into three zones by Bell (1938). These zones, recognized on the basis of their megaflora, were mapped across the eastern part of the basin by Hayes et al. (1938) and extended to the west by Bell and Goranson (1938). The two lower zones, the *Linopteris obliqua* and *Lonchopteris* zones are distinct from the upper, *Ptychocarpus unitus* zone by the presence of economic coal seams in the latter. According to Barss and Hacquebard (1967), the three megafloral zones correspond to distinct spore assemblages (Table 1).

This report is part of a large project which aims to establish lithostratigraphic subdivisions for the Morien Group throughout the Sydney Basin, and examine its sedimentology in detail. The report is based on the study of coastal sections, drill core and drillhole data from the lower two zones (the lower Morien Group) for the northeastern coast of Cape Breton Island between Bateston (eastern end of Bateston Fault) and Cap Percé (Fig. 1). About 10 per cent of the coastal section is inaccessible even at low tide. These sections were studied by close-up reconnaissance from a boat, and by analysis of photographs. Over 150 rock samples were collected, including 80 for petrographic analysis, 30 for X-ray diffraction and 25 submitted to M. S. Barss, Atlantic Geoscience Centre, Geological Survey of Canada, for spore analysis. A 332 m core from the study area was

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* Also in Current Research, Part A, Geological Survey of Canada, Paper 83-1A, p. 183-186, 1983.

* Contribution to Canada-Nova Scotia Co-operative Mineral Program 1981-84. Project carried by Nova Scotia Department of Mines and Energy and by Geological Survey of Canada.

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Table 1. Table of stratigraphic units within the Morien Group (formerly Series) of Cape Breton Island, Nova Scotia

	Age	Robb (1876)	Hayes, Bell and Goranson (1938)	Barss and Hacquebard (1967)
UPPER CARBONIFEROUS (Pennsylvanian)	Westphalian D	Productive Coal Measures	*Ptychocarpus unitus* zone	*Thymospora* zone C
	Westphalian C	Millstone Grit	*Linopteris obliqua* zone	*Torispora* zone B
			Lonchopteris zone	*Vestispora* zone A

logged, as well as pertinent sections of two other cores from the area. As far as possible, the core data will be correlated with the coastal sections.

STRUCTURE

Hayes et al. (1938) mapped the structure of this area as a series of simple east-west folds, with a major east-west fault at the southern margin of the Morien Group outcrop (the Bateston Fault). The folds are locally asymmetric, notably the Cap Percé Anticline and the Port Morien Syncline (located 2 km to the southeast), whose northern limb dips up to 45 degrees, but whose southern limb dips at about 10 degrees.

Offshore drilling and geophysical work over the last decade have shown that the structure of the area is more complex, with several faults in Morien Bay (Hacquebard, 1983). Another, previously unrecognized feature is that the strike of strata on either side of Cape Morien indicate that the headland coincides with the axis of an eastward-plunging syncline. This necessitates the presence of an anticline in the southern part of Morien Bay. Apart from this complication, and some minor faults, the coastal sections are remarkable for their lack of tectonic disruption.

STRATIGRAPHY

A summary of previous and existing stratigraphic nomenclature for the Morien Group in the Sydney Basin is given in Table 1. As discussed later, the lower part of the succession on the eastern coast, that extending south of False Bay, is characterized by a sandstone-rich facies association. To the north of False Bay the strata comprise a facies association in which subequal sandstone and mudrocks alternate, commonly in erosionally-based, fining upward sequences.

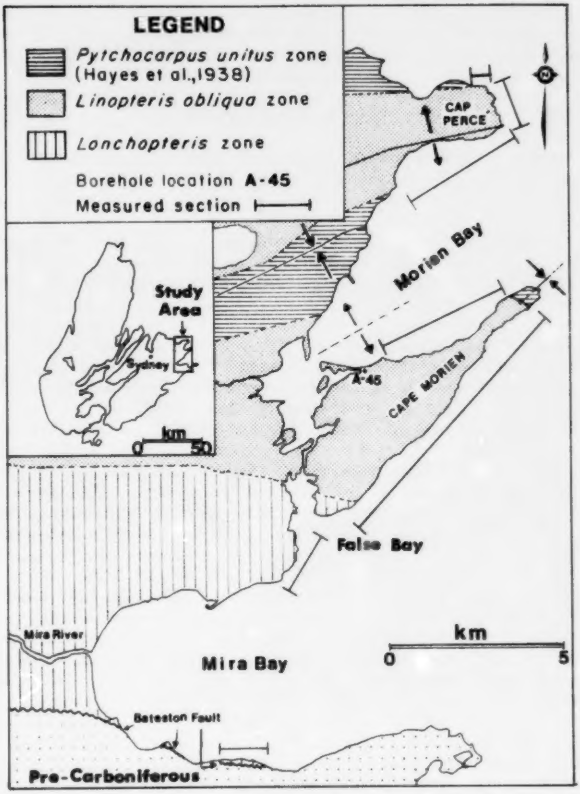
LEGEND
Pytchocarpus unitus zone (Hayes et al.,1938)
Linopteris obliqua zone
Lonchopteris zone
Borehole location A-45
Measured section
Study Area
Sydney
km
0
50
CAP PERCE
Morien Bay
A-45
CAPE MORIEN
False Bay
Mira River
Mira Bay
km
0
5
Bateston Fault
Pre-Carboniferous

Figure 1. Location map for eastern part of Sydney Basin.

The outcrop at Bateston is isolated from the main Morien Group outcrop by an extensive unexposed area. It is steeply dipping and partly overturned due to proximity to the Bateston Fault. The succession is predominantly sandstone, and its assignment to the lower part of the Morien Group by Hayes et al. (1938) seems appropriate.

The boundary between the middle *(Linopteris obliqua)* and the upper *(Ptychocarpus unitus)* zones of Hayes et al. (1938) was delineated at the base of the Spencer seam, equivalent to the Emery seam of the northern outcrops. This may also be regarded as a lithostratigraphic boundary, for it marks the lowest horizon of the more abundant economic coal seams in the upper part of the Morien Group. However, the eastern coast section discussed here does not reveal any significant difference between the clastic successions above and below the Spencer-Emery seam. In any case, proper identification of lithostratigraphic units must await the completion of data analyses from the whole of the Sydney Basin.

Facies Descriptions

The principal facies of the Morien Group in the Port Morien (located at the southern end of Morien Bay) area are as follows (after Miall, 1978):

Facies Gm Massive to crudely stratified polymictic clast-supported conglomerate. Clasts are well rounded; quartz is the most abundant clast type. The facies occurs as thin lag deposits at some channel bases.

Facies Se Erosional scours with intraclasts in a sandstone matrix are present at most channel bases. The sandstone is medium grained to granule-bearing; the intraclasts are commonly grey to tan coloured siderite nodules 0.5 cm to 2 cm in diameter. Less abundant are mudstone intraclasts, but carbonized plant fragments are common.

Facies St Trough cross-stratified sandstone is the most abundant facies, forming the bulk of the channel deposits. The sandstone varies from fine- to coarse-grained, but is predominantly medium or fine. Troughs range in thickness from 3 cm to 70 cm, but are mostly between 10 cm and 25 cm thick.

Facies Sr Ripple crosslaminated fine grained sandstone occurs towards the top of many channel-fill sequences (commonly interstratified with facies Sh), as well as in levee and crevasse-splay deposits. Ripples vary up to 3 cm in height. Some wavy-laminated fine sandstones are probably Sr units that have been deformed by compaction of interlayered thin mudstone units.

Facies Sh Horizontally stratified fine grained sandstone commonly occurs interstratified with facies Sr in the upper parts of channel sequences. This facies is characterized by primary current lineation.

Facies Sp Planar/tabular cross-stratified sandstone is a relatively uncommon facies. Sandstone grade varies from fine- to coarse-grained, and set thickness varies from 5 cm to 50 cm.

Facies Fl This facies includes interlaminated fine grained sandstone, siltstone, and mudstone. The mudstone is commonly red to grey, with green mottles which commonly are tubular or spherical, resulting from differential reduction in relation to plant fragments or roots.

Facies Fm This facies consists of massive red to grey mudstone, siltstone, and silty fine sandstone. It contains desiccation cracks and rare raindrop imprints. Some units of this facies display a pattern of deep (up to 0.7 m) interconnected cracks, which may be a pedogenic feature.

Facies Fr This facies consists of massive fine grained deposits with rootlets, interpreted as seat earths, even if no coal overlies them. The facies is common, although it does not form a large part of the succession.

Facies C Coal recurs throughout the succession, in beds varying from less than 1 cm to 2 m in thickness. It commonly underlies channel sandstones.

Facies Associations

Two facies associations have been observed, one which is sandstone dominated, the other in which sandstone and mudrocks occur in approximately equal proportion. There is no faunal or sedimentological evidence for marine incursion in either association, and the repetition of paleosols, rooted horizons, raindrop imprints, mudcracks, and coals indicates terrestrial deposition.

The sandstone facies association is present in the 140 m succession south of False Bay, and at Bateston. The associated facies, in order of decreasing abundance are Se, St and Sr-Sh, with minor amounts of Sp and rare Fl-Fm, Fr and C. Figure 2 is a typical measured section from this facies association. It shows poorly defined upward-fining sequences, in which an erosion surface (Se) is overlain by trough cross-stratified sandstone (St) and minor fine grained facies. The succession resembles facies association S_{II} of Rust (1978), and is interpreted as the deposit of a distal braided fluvial system. A modern analogue is the South Saskatchewan River described by Cant (1978), although the lateral extent of the Morien Group indicates that it was deposited on a braidplain. Locally, the plain probably showed transition to a meandering channel pattern.

To the north of False Bay the assemblage contains a significantly higher proportion of mudrocks (Fig. 3). Facies St, Sh, Sr and Fl-Fm are dominant, with minor amounts of facies Se, Sp, Fr and C. Sequences within the succession are generally clearly differentiated into channel or overbank deposits. Facies St is dominant in channel sequences, within which it is commonly interspersed with facies Sh, and fines upward to Sr. Facies Sr also occurs in levee sequences, characterized by upright tree trunks, and crevasse-splay sequences. Facies Sh is also present in levee and crevasse-splay sequences, together with the Fm-Fl combination. The latter is the dominant facies of overbank sequences away from levee and crevasse-splay sandstones. Lesser amounts of seat earth and coal are also found in overbank sequences, commonly close to or immediately beneath the succeeding channel sandstone.

The facies association described above is attributed to deposition by an alluvial system dominated by meandering channels. Channel accretion by lateral migration is confirmed by the presence of lateral accretion surfaces in several of the channel sequences.

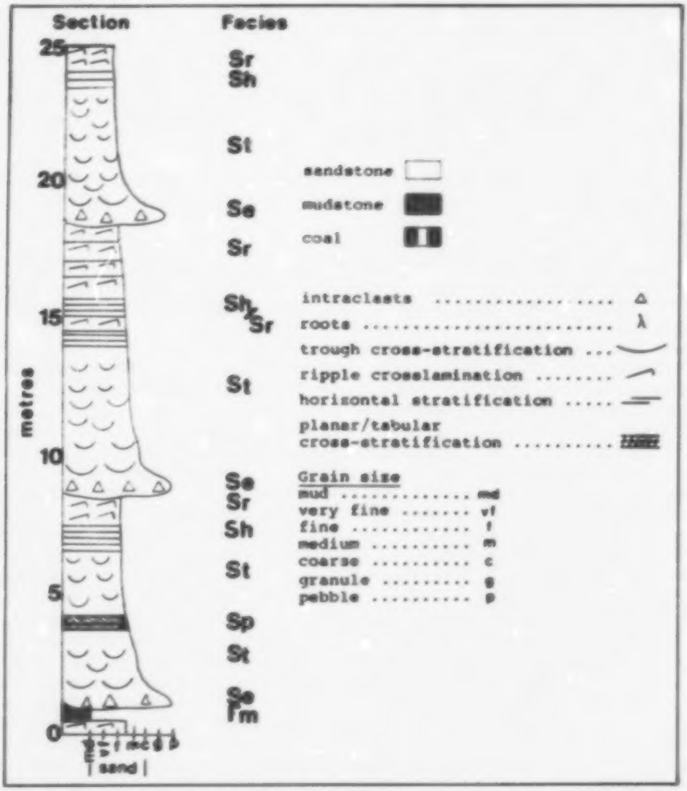
Section
Facies
25
20
15
10
5
0
metres
Sr
Sh
St
Se
Sr
Sh
Sr
St
Se
Sr
Sh
St
Sp
St
Se
Fm
md
vf
f
m
c
g
p
sand
sandstone
mudstone
coal
intraclasts .... △
roots .... λ
trough cross-stratification ...
ripple crosslamination ....
horizontal stratification .....
planar/tabular cross-stratification ....
Grain size
mud .... md
very fine .... vf
fine .... f
medium .... m
coarse c
granule .... g
pebble .... p

Figure 2. Composite section of sandstone facies assemblage south of False Bay.

Approximately 300 paleocurrent readings were recorded from facies St, Sr and Sh in the Morien Group of the Port Morien area. Figure 4 shows the data for trough cross-strata, because these are considered to be the most reliable of the paleocurrent indicators present. The mean orientation is towards the north (019°) with a vector magnitude of 83 per cent. The crossbed data indicate that paleoflow from the south or southwest was maintained throughout deposition of the Morien Group in this area. A similar picture is emerging for the whole of the Sydney Basin (Rust et al., this volume), although analysis is not yet complete.

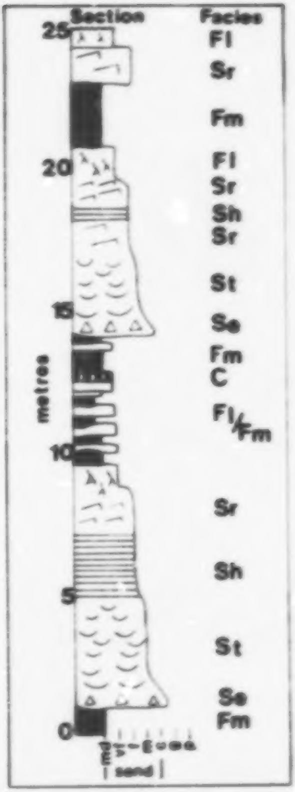

Figure 3. Composite section of alternating facies assemblage north of False Bay. (see Figure 2 for legend).

The Morien Group succession at the eastern margin of the Sydney Basin shows an upward change from a distal sandy braidplain to an alluvial plain with fewer, larger, high-sinuosity channels. As this change took place, there was a significant increase in the proportion of the alluvial plain on which fine grained sediment accumulated. The thickness of fine grained sequences also increased. As a result, local compaction of sediment became an increasingly important factor in the evolution of the basin, superimposed on continuing regional subsidence. Compaction produced depressions on the floodplain in which plant material accumulated, in some cases to the extent that thick, widespread peat was formed. At the present time it is not clear why the conditions for peat accumulation became more frequent and lasted longer during late Morien times, in contrast to the apparently similar preceding environment. However, it is expected that integration of data from all parts of the Sydney Basin will aid in answering this question.

FURTHER WORK

The large amount of data collected during 1982 has not yet been fully analysed. The remaining tasks are:

1. completion of stratigraphic sections: coastal and boreholes;

2. correlation of coastal and borehole sections throughout the area and into the rest of the Sydney Basin; and

3. petrographic and XRD analysis of lithological specimens. In addition to better description of facies types, this analysis will be used to investigate diagenetic history.

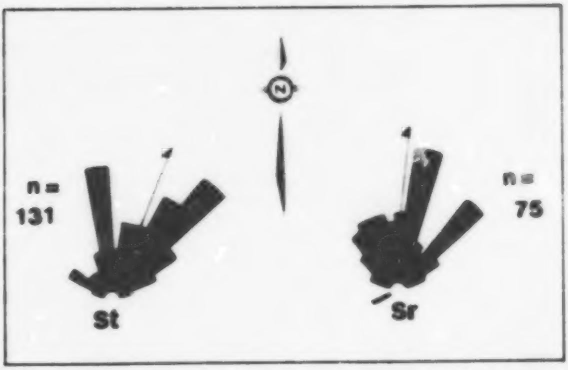

Figure 4. Paleocurrent data from eastern coast sections between Cap Percé and Mira River based on trough cross-strata (facies St) and ripple crosslamination (facies Sr). Arrows indicate mean vector azimuth, n indicates number of observations.

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SEDIMENTOLOGICAL STUDIES IN THE SYDNEY BASIN, 1982*

B. R. Rust**, G. Masson**, S. Dilles**,

and

M. R. Gibling***

ABSTRACT

Three facies assemblages have been recognized in the alluvial Morien Group (Westphalian C-D age) of the Sydney Basin, Nova Scotia. The pebbly sandstone assemblage is characterised by thin pebble conglomerate units, a paucity of mudrocks and a lack of in situ coal. It is attributed to deposition on a moderately high energy braidplain. The sandstone assemblage, containing thin granule conglomerates, minor coals and about 10% mudrocks is interpreted as a distal braidplain deposit. The third assemblage, mainly comprising alternations of mudrocks and fining upward sandstone sequences, is attributed to deposition on a meandering fluvial plain. Mudrocks make up about 50 per cent of the succession and contain significant coal seams, due to the formation of thick peats as floodplain mud sequences compacted. The alternating assemblage was initiated earlier in the eastern part of the basin than in the western part, but developed fewer, thinner coal seams at that time.

Paleocurrent studies indicate consistent northeastward transport through space and time. There is little indication of basement influence at present basin margins, implying that the basin formerly extended further to the southwest. A basement high along the Boisdale Anticline apparently influenced paleodrainage in the southern Boularderie Island area.

REPORT ON SYDNEY BASIN PROJECT, 1982

Introduction

This project is a study of the Upper Pennsylvanian Morien Group in the Sydney Basin, Nova Scotia, undertaken jointly with the Nova Scotia Department of Mines and Energy and the Geological Survey of Canada. The present report is concerned with an investigation of the stratigraphy and sedimentology of the lower part of the Morien Group throughout the Sydney Basin and the upper Morien in that part of the basin east of Sydney Harbour (Fig. 1).

Detailed sections were measured for all coastal exposures of any significant extent from Mira Bay to Sydney Harbour. With the exception of about 10 per cent of the Cap Percé and South Head shorelines, all these sections are accessible at low tide, even if only for a short period of

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*Contribution to Canada-Nova Scotia Co-operative Mineral Program 1981-84. Project carried by Nova Scotia Department of Mines and Energy and by Geological Survey of Canada.

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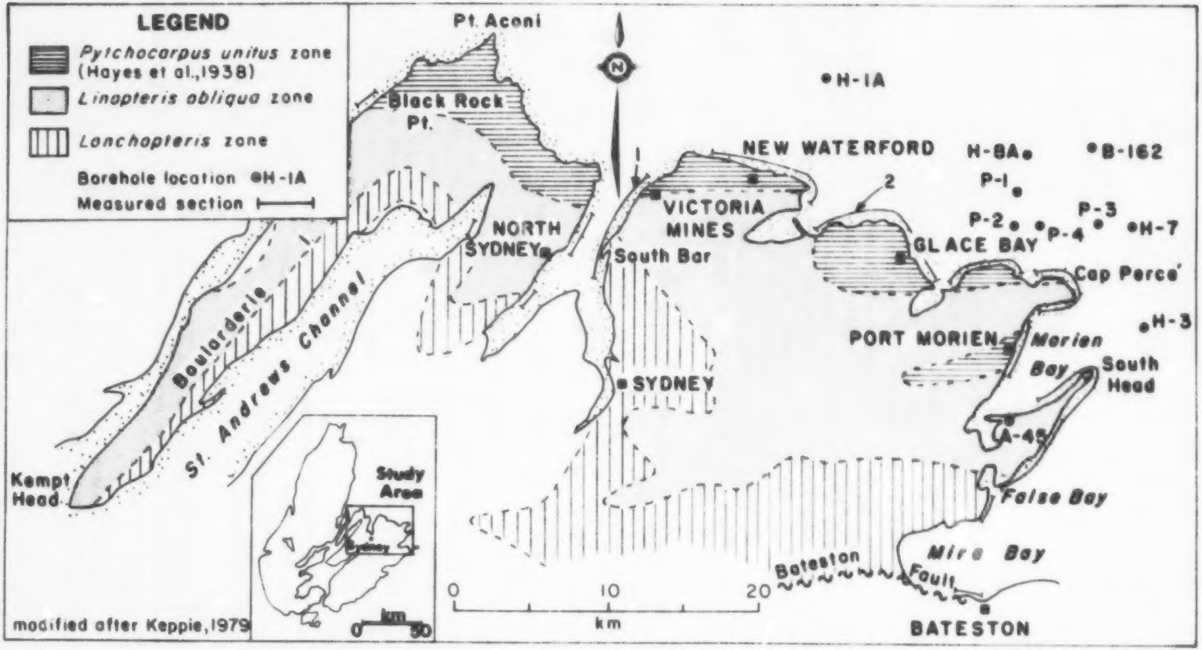

LEGEND
Pytchocarpus unitus zone (Hayes et al.,1938)
Linopteris obliqua zone
Lanchopteris zone
Borehole location ●H-1A
Measured section
Pt. Aconi
Black Rock Pt.
●H-1A
NEW WATERFORD
H-8A
●B-162
P-1
P-2
P-3
P-4
●H-7
1
2
VICTORIA MINES
NORTH SYDNEY
South Bar
GLACE BAY
Cap Perce
●H-3
PORT MORIEN
Morien Bay
South Head
SYDNEY
A-45
Boulardarie
St. Andrews Channel
Kempt Head
Study Area
Sydney
km
0
50
False Bay
Mira Bay
Bateston Fault
BATESTON
0
10
20
km
modified after Keppie,1979

Figure 1. Location map of Sydney Basin, Cape Breton Island.

time. The inaccessible shorelines were investigated by close-in approach by boat, and by analyses of photographs taken from the boat. Exposures around Boularderie Island and at Cape Dauphin are discontinuous, so with some exceptions sections were not measured in these areas. In all cases detailed observations of lithology, paleocurrents and facies types were made. In addition, ten boreholes (Fig. 1) were logged, varying in depth penetrated from 30 m to 150 m.

Bell (1938) recognized three zones within the Morien Group on the basis of its megaflora, which Barss and Hacquebard (1967) equated with spore assemblages (Table 1). Boundaries between these biostratigraphic zones were mapped across the Sydney Basin by Hayes et al. (1938) and Bell and Goranson (1938a, b, c). The boundary between the lower *(Lonchopteris)* and middle *(Linopteris obliqua)* zones was drawn at the Tracy seam, and that between the middle and upper *(Ptychocarpus unitus)* zones at the Spencer or Emery seam by Hayes et al. (1938). These authors did not indicate that any other lithostratigraphic criteria were taken into account in the subdivision. A similar situation prevails in the western part of the Sydney Basin. The present study aims to establish lithostratigraphic units throughout the Basin and to investigate depositional environments in relation to coal accumulation.

Table 1. Table of stratigraphic units within the Morien Group (formerly Series) of Cape Breton Island, Nova Scotia

	Age	Robb (1876)	Hayes, Bell and Goranson (1938)	Barss and Hacquebard (1967)
UPPER CARBONIFEROUS (Pennsylvanian)	Westphalian D	Productive Coal Measures	*Ptychocarpus unitus* zone	*Thymospora* zone C
	Westphalian C	Millstone Grit	*Linopteris obliqua* zone	*Torispora* zone B
			Lonchopteris zone	*Vestispora* zone A

PETROGRAPHY AND FACIES TYPES

Rust and Masson (1981) outlined the petrography of the principal rock types of the upper Morien Group in the Port Morien and Victoria Mines areas. Subsequent work has shown that these rock types are found throughout the Sydney Basin, but in differing proportions. Petrographic analysis is not yet complete in other areas, but facies have been recognized on the basis of gross lithology and the sedimentary structures present, using in most cases the classification of Miall (1978). Complete integration of field and laboratory analysis must await completion of petrographic work, but a simplified listing of facies types follows:

1. Conglomerate to very coarse lithic and sublithic sandstone; massive to crudely horizontally stratified (Gm).
2. Coarse- to fine-grained (mainly medium grained) lithic and sublithic sandstone; trough cross-stratified (St).
3. Medium- to fine-grained (mainly fine grained) sublithic sandstone, horizontally stratified, with primary current lineation (Sh).
4. Fine to very fine sublithic to quartz sandstone; ripple crosslaminated (Sr).
5. Very fine sandstone/siltstone/shale interlaminated (Fl).
6. Massive silty mudstone (Fm).
7. Limestone.
8. Sideritic, calcitic or silicic nodules, some of which are pedogenic (P).
9. Coal, carbonaceous shale (C).

Rust and Masson (1981) outlined preliminary petrographic descriptions of these facies types, and related lithofacies assemblages to the codes of Miall's (1978) classification. The facies types recognized after additional field work are essentially the same as those described previously, and may be summarized as follows:

Gm: This facies comprises massive to crudely bedded pebble to granule conglomerate with coarse sandstone matrix, which in some cases is present in sufficient quantity to produce a matrix supported texture. Commonly this facies forms thin lags at channel bases, and includes tree trunks, peat mats, intraclasts of mudstone and siderite nodules. At Cape Dauphin and Boularderie, where the base of the Morien Group is exposed, facies Gm forms thicker (up to 2.3 m) more consistent units, rather than lags.

St: Trough cross-stratified sandstone is the most common facies of the lower part of the Morien Group (the *Linopteris obliqua* and *Lonchopteris* zones of Bell, 1938). It is mainly medium- to coarse-grained, locally pebbly, in solitary or (more commonly) grouped trough sets that are up to 70 cm thick, but are mostly less than 40 cm thick. The bases of grouped sets (and some solitary sets) commonly have intraclast or plant lags.

Sp: Planar-tabular cross-stratified sandstone is relatively uncommon. It occurs as solitary (rarely grouped) sets a few decimetres thick, but some sets are exceptionally thick such as the 2.6 m set at the top of the Bateston section. This set is pebbly, and has intrasets of smallscale troughs.

Sh: Horizontally stratified sandstone occurs sporadically throughout the sections, but is only abundant locally. It commonly bears primary current lineation, unless disturbed by bioturbation. In some cases it is transitional into low-angle, current lineated sandstone (facies Sl of Miall, 1978).

Sr: Ripple crosslaminated fine grained sandstone is the dominant facies of the upper part of the Morien Group (zone *Ptychocarpus unitus* of Bell, 1938). The ripples are asymmetric, current formed types, showing considerable variation in size, cross-sectional shape and crest pattern. Variable amounts of shale lenses (flasers) are present in some Sr units. Bioturbation and load deformation are common.

Fl: Interlaminated shale, siltstone and very fine grained sandstone are abundant in the upper part of the Morien Group, but less common in the lower Morien. Ripple crosslamination, burrows, plant rootlets and pedogenic nodules are locally common in this facies.

Fm: Massive mudstone occurs in close association with facies Fl. In some cases the massive nature is due to destruction of lamination by bioturbation, and in these cases the two facies are grouped as Fl/Fm.

Limestone: Nonpedogenic limestone units, for which there are no suitable facies codes in Miall's (1978) nomenclature, are present in the upper part of the Morien Group. They vary from essentially massive micritic limestone to well laminated fossiliferous limestones to stromatolites. The fossils including ostracods, bivalves, gastropods and stromatolites, are the nonmarine type. The limestone units are interpreted as lacustrine deposits. Also included in this facies are calcite cemented massive sandstones.

P: Nodules of siderite or, less commonly, silica or calcite are scattered throughout the fine grained facies. The siderite nodules probably formed diagenetically in waterlogged sediment. Many of the calcite and silicic nodules are concentrated in layers, and show features characteristic of subaerial, pedogenic origin. In some cases nodules are associated with alteration around plant roots (rhizoliths; Klappa, 1980).

C: Coal or carbonaceous shale occurs throughout the Morien, but is present as thicker, more common seams in the upper part of the Group. The coal commonly overlies a rooted seat earth.

FACIES ASSEMBLAGES

A facies assemblage is a group of facies which tend to occur together in vertical sequence in certain proportions. Taken together, the assemblages can be used to interpret the depositional environment of a sedimentary succession.

Pebbly Sandstone Facies Assemblage

The longest continuous section in the area studied is that from South Bar to Victoria Mines (Fig. 1), which contains over 900 m of strata. The lowest 105 m of this section are dominated by sandstone, with only 3.0 m of mudrocks present (Fig. 2). Another characteristic of this part of the section is presence of thin (commonly less than 30 cm thick) small to medium pebble conglomerate units (facies Gm) above erosion surfaces. These units are basal lags, and often contain intraclasts of mudstone or siderite nodules, carbonized logs and coal mats. An exceptional case is a 2.3 m thick small pebble conglomerate unit, whose base is at 4 m in the South Bar section.

The conglomerate lags are in most cases sharply transitional upwards to cosets of trough cross-stratified medium grained sandstone (facies St). In most cases, units of St do not show upward gradation in grain size, nor upward change in the scale of trough sets. Intraclasts and carbonized plant material are present sporadically in some units of facies St. Trough sets associated with plant material are deformed, mainly due to disturbance of surrounding sediment when logs or peat mats compacted to form coal. This lowest part of the South Bar-Victoria Mines section is characterized by a coarse sandstone facies assemblage. Despite the virtually continuous outcrop, no coal seams were observed.

Sandstone Facies Assemblage

From 105 m to 739 m the South Bar-Victoria Mines succession continues to be sandstone dominated, and is typical of the sandstone facies assemblage. It differs from the assemblage described above in several minor features (Fig. 3). Lag deposits are composed of granule conglomerate rather than small to medium pebble conglomerate. Mudstone units are more abundant than in the coarse grained (pebbly) sandstone assemblage, amounting to approximately 10 per cent of the succession. Flute and groove casts are common on sandstone surfaces overlying mudstone. Another contrast is the presence of thin coal seams which are absent from the coarse assemblage. Minor rippled fine grained sandstone and horizontally stratified sandstone are also very uncommon facies in the pebbly sandstone assemblage.

St is once again the dominant facies, and is essentially identical to that described for the pebbly sandstone assemblage. However, in this case cosets of facies St tend to show grain size gradation, both from underlying granule bearing lags and upwards into facies Sr, if present. As in the pebbly sandstone assemblage, St cosets are commonly deformed by differential compaction of organic material.

Alternating Facies Assemblage

The third facies assemblage occupies the upper part of the Victoria Mines section (above 739 m) and is characterized by an alternation of sandstone and mudrock sequences (Rust and Masson, 1981). Mudrocks, with

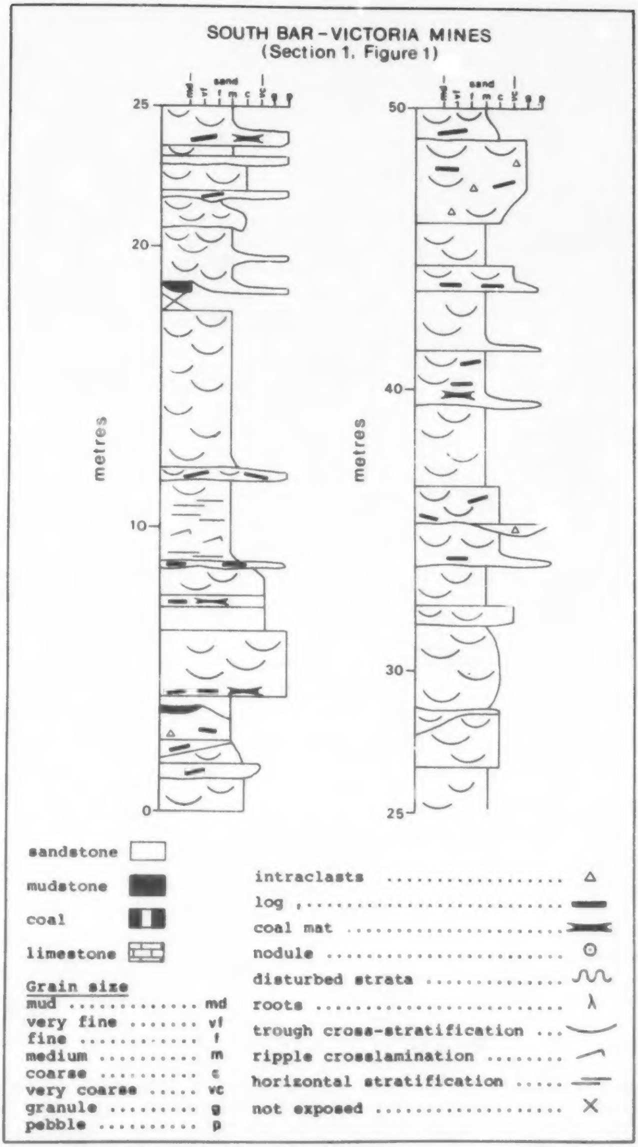

SOUTH BAR - VICTORIA MINES
(Section 1, Figure 1)
md
vf
f
m
c
vc
g
p
sand
metres
0
10
20
25
30
40
50
sandstone
mudstone
coal
limestone
Grain size
mud .... md
very fine .... vf
fine .... f
medium .... m
coarse c
very coarse vc
granule .... g
pebble .... p
intraclasts ....
log ....
coal mat ....
nodule ....
disturbed strata ....
roots ....
trough cross-stratification ...
ripple crosslamination ....
horizontal stratification .....
not exposed ....

Figure 2. Stratigraphic log from lower part of South Bar-Victoria Mines section (section 1, Fig. 1) showing strata characteristic of the pebbly sandstone facies assemblage.

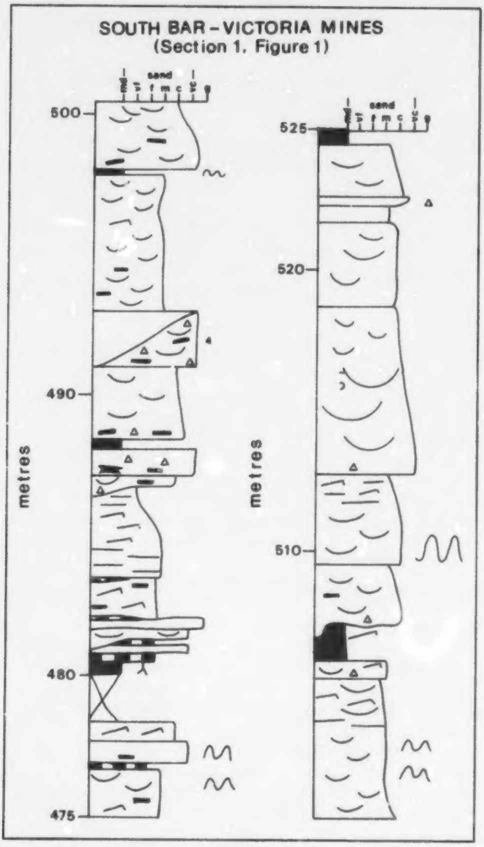

SOUTH BAR - VICTORIA MINES
(Section 1, Figure 1)
sand
f m c
500
490
480
475
525
520
510
metres
metres

Figure 3. Stratigraphic log from middle part of South Bar-Victoria Mines section (section 1, Fig. 1), showing strata characteristic of the sandstone facies assemblage. See Figure 2 for legend.

minor coals and limestones, commonly make up at least 50 per cent of any section, but their true abundance is probably greater, because of their recessive weathering. The typical sandstone sequence is about 5 m thick, and fines upwards from a distinct erosional base overlain by a lag deposit containing plant fragments and intraclasts of mudstone or siderite nodules. The sandstone above the lag grades from medium- to fine-grained as the facies grade from St to Sr. Thin units or lenses of facies Sh may also be present at various levels within this sequence.

In contrast, coarsening-upward units are much less common, and are in addition thinner and finer grained (Fig. 4). Typically they are about 1 m thick, and grade upward from mudstone to siltstone, or from siltstone to very fine or fine sandstone. The dominant internal structures are ripples; plant roots are also present in most cases.

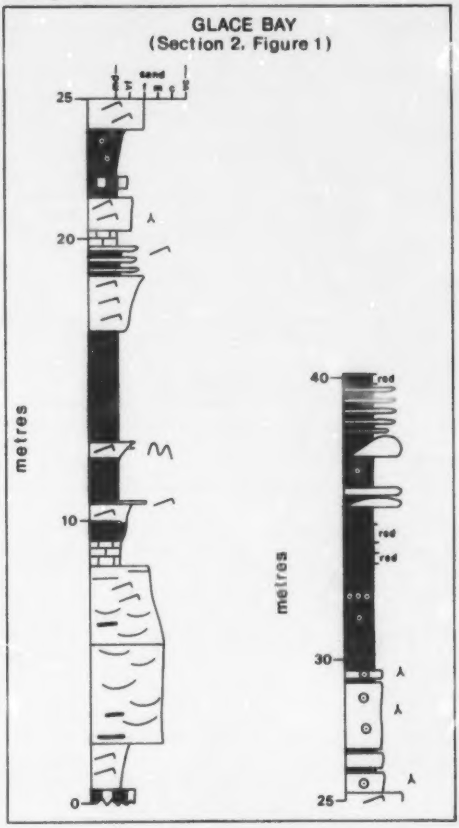
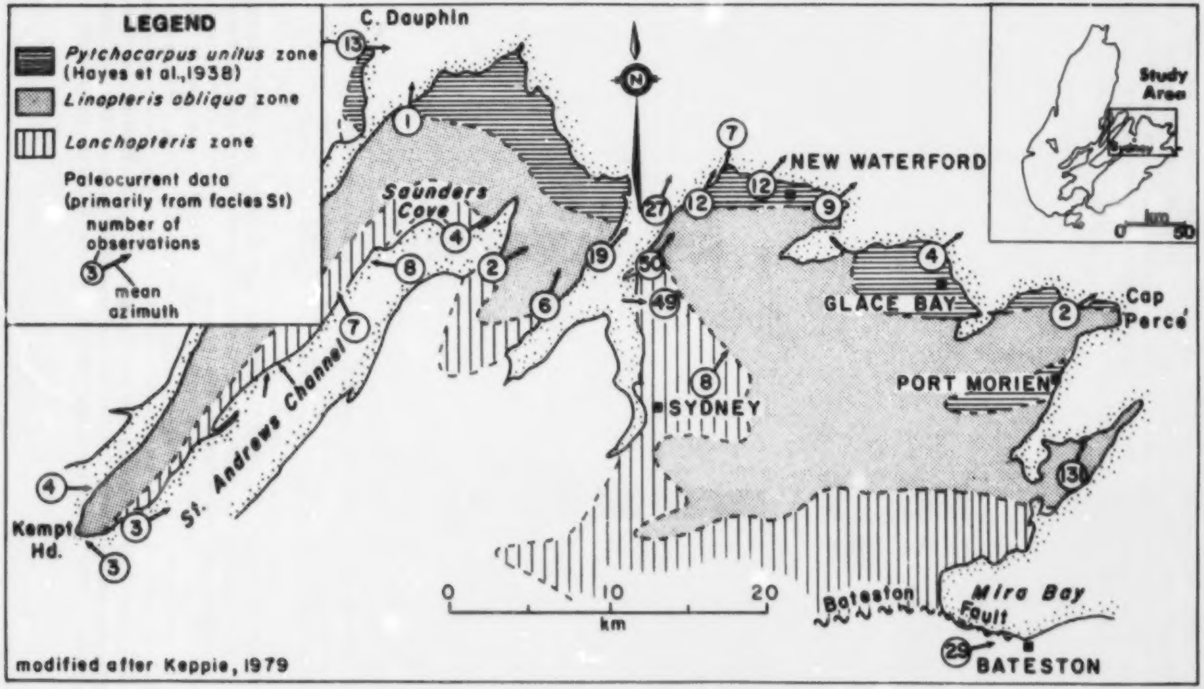


Figure 4. Stratigraphic log from the Glace Bay section (section 2, Fig. 1), showing strata characteristic of the alternating facies assemblage. See Figure 2 for legend.

Paleocurrents

Paleocurrent data are expressed in Figure 5 as mean azimuths for local areas, with adjacent numbers indicating the number of observations included for each mean. The most striking result is the general uniformity of


LEGEND
Pytchocarpus unitus zone (Hayes et al.,1938)
Linopteris obliqua zone
Lonchopteris zone
Paleocurrent data (primarily from facies St)
number of observations
mean azimuth
C. Dauphin
Saunders Cove
St. Andrews Channel
Kempt Hd.
NEW WATERFORD
GLACE BAY
Cap Percé
PORT MORIEN
SYDNEY
Mira Bay
Bateston Fault
BATESTON
Study Area
Sydney
km
0
50
0
10
20
km
N
13
1
4
2
8
7
6
19
27
12
7
12
9
50
49
8
4
2
13
29
3
3
4
3

modified after Keppie, 1979

Figure 5. Map of Sydney Basin showing mean paleocurrent vectors for trough cross-strata in the Morien Group.

paleocurrents towards the northeast for all stratigraphic levels in the Morien Group. We do not have data for the coasts east and west of Point Aconi, but Duff et al. (1982) showed that the paleocurrent trend is also northeastward in this region. Our data are all predominantly based on paleocurrents measured in facies St. Duff et al. (1982) did not indicate the types of cross-strata measured, but they probably were predominantly trough cross-strata.

The only consistent local deviation from the northeastward trend is the appearance of northwestward mean azimuths on the eastern coast of Boularderie Island, and at Kempt Head, on its southwestern tip. These paleocurrents suggest the influence of a positive feature in St. Andrews Channel, probably a southward continuation of the Boisdale Anticline, which crosses the coast a few kilometres west of Point Aconi and intersects St. Andrews Channel at Saunders Cove (Bell and Goranson, 1938b, c). Hacquebard (1983) showed that this Anticline is an important feature of the offshore structure, dividing the Basin into two subbasins.

The paleocurrent data give little other indication of basement control on paleodrainage patterns in the Sydney Basin. For example, the eastward mean azimuth at Bateston indicates that the sediments were not derived from basement rocks lying to the south. This implies that the present faulted margin of the Basin at Bateston is a post-Morien feature. Paleocurrents at Black Rock Point imply a similar conclusion for the presumed faulted margin along Great Bras d'Or. A possible exception to this generalization is the eastward paleocurrent direction at Cape Dauphin, which is directed away from adjacent basement rocks.

DEPOSITIONAL ENVIRONMENTS

The presence of coals, paleosols (including in situ rooted horizons) and upright trunks indicate that the Morien Group was deposited in a terrestrial environment. There is no evidence for marine incursion; marine fossils are lacking, as are thick coarsening-upward deltaic sequences. Fossils are locally abundant in calcareous bands or limestones closely associated with coal seams in the upper part of the Morien Group. The fossils are all of nonmarine origin.

The facies present and their assemblages can all be assigned to deposition on an alluvial plain. From time to time, particularly towards the end of Morien Group deposition, depressions on the floodplain gave rise to extensive peat swamps, or to lakes in which algal stromatolites, ostracods and other organisms flourished.

The progressive development of the alluvial plain is indicated by the succession of facies assemblages observed in the coastal sections. The pebbly sandstone assemblage represents the most proximal alluvial conditions; a braidplain on which a significant amount of gravel was transported. Mud accumulated in places, but was rarely preserved, except in the form of intraclasts within channel lag deposits. The braidplain supported moderately large plants, and permitted small peat swamps to form. Like the mud deposits, however, the peat was not preserved in place, and is only present as transported peat rafts (now coal).

In terms of the braided alluvial models discussed by Rust (1978) the pebbly sandstone assemblage of the Morien Group appears to lie between S_I (proximal, high slope) and S_{II} (distal, low slope sandy braidplains). Features that resemble S_I successions are the poor development of grading and cyclicity, and the abundance of erosion surfaces, mudstone intraclasts and peat mats. Features indicative of more distal character are the presence of relatively large plants and the paucity of gravel, although the latter may be partly a function of provenance.

The sandstone facies assemblage can be more easily categorised. With its tendency to cyclicity, and the presence of minor mudstones and coals it can be assigned with reasonable confidence to a low slope, distal braidplain. Amongst existing models, it most closely resembles the South Saskatchewan model of Cant (1978) and Miall (1978). One important difference is that facies Sp plays an important part in the South Saskatchewan model, but is rare in the Morien Group. This is probably a function of deeper channels in the Morien Group, in which trough sets formed, but the shallow water sand flats generating sets of Sp facies were developed more rarely.

The alternating facies assemblage has many features characteristic of meandering river deposits. Rust and Masson (1981) enumerated these features for the Port Morien and Victoria Mines sections. Further work has shown that they are found elsewhere in the upper part of the Morien Group, and extend into the middle part of the succession in the Port Morien-Mira area. The most critical diagnostic features follow:

1. Fining upward sandstone sequences averaging about 5 m thick with erosional base, commonly overlain by an intraclastic lag. The lag fines upward to facies St, then Sr and then passes to Fm, Fl or other fine grained facies. These sequences are interpreted as point bar deposits on the basis of the sequence of facies, structures, and grain size gradation.

2. In cliff exposures many of the point bar sequences show lateral accretion bedding in the form of gently sloping surfaces that pass right through the sequence, and are made visible by somewhat finer grain size. In cases where the dip direction of the lateral accretion surface can be determined, it is approximately perpendicular to the paleocurrent direction indicated by troughs in the point bar sequence. The presence of lateral accretion features strongly corroborates the meandering river point bar interpretation.

3. A few mudstone filled paleochannels are present. They represent clay plugs formed by accumulation of mud from suspension as flood waters inundated an abandoned meander. These paleochannels show a high depth to width ratio, characteristic of meandering channels (Schumm, 1963). Channel abandonment could have been due to neck cutoff, chute cutoff, or avulsion (Walker and Cant, 1979).

4. Minor thin, coarsening-upward units are attributed to the progradation of facies Sr in levees or crevasse splays across the floodplain. Levees are characterized by stands of mature vegetation, represented by erect trunks.

5. Floodplain deposits are represented by mud rich sequences, rooted horizons and coals. In the latter case, compaction of the floodplain mud proceeded at a rate suitable for the accumulation of peat. Sideritic nodules (which indicate reducing conditions) and lacustrine deposits also developed from time to time, the later controlled largely by rate of subsidence (high rate caused lacustrine transgression).

EVOLUTION OF THE SYDNEY BASIN

As discussed previously, paleocurrent data indicate that major faults along the western and southeastern margins of the Sydney Basin formed subsequent to deposition. This indicates that the Basin originally extended further to the southwest, where coarser, basin-margin facies assemblages may have developed.

The coarsest deposits in present outcrops (the pebbly sandstone facies assemblage) are limited to western and southwestern parts of the Basin, extending no further to the northeast than South Bar. These were deposited on a braidplain of moderate energy and slope, on which peat units were formed, but not preserved in place. Paleocurrents on Boularderie Island indicate basement control by what was probably the Boisdale Anticline. At the present level of knowledge it is not possible to propose this sedimentary package as a formal lithostratigraphic unit. Integration of data from inland outcrops and borehole data is required before this can be done.

The pebbly sandstone facies assemblage is transitional upwards into the sandstone assemblage. This transition represents gradual decrease in slope and energy on the braidplain. These deposits occur well up the stratigraphic succession in the western and central parts of the Basin, but in the presumed lowest strata (south of False Bay and at Bateston) on the eastern coast.

The lithostratigraphic change from the sandstone to the alternating facies assemblage is close to the mapped boundary between the *Ptychocarpus* and *Linopteris* zones in the western and central parts of the basin. In sections, at Sydney Mines, Victoria Mines and Lingan, the logical horizon for this boundary is the base of a major fine grained unit that contains the coal seam chosen as the boundary by Hayes et al. (1938) and Bell and Goranson (1938a, b). In fact, this boundary is within 10 m below the appropriate seam chosen by these authors (Spencer/Emery seam). On the eastern coast, however, the change from sandstone to alternating facies assemblage occurs much lower in the succession, in the vicinity of False Bay. This lithostratigraphic change is significantly below the *Ptychocarpus/Linopteris* boundary of Hayes et al. (1938). The only other coastal exposure of this zonal boundary is west of Schooner Cove, but it is too thin to determine the facies assemblage reliably. However, the dominance of facies Sr in this succession suggests that the alternating assemblage is represented.

In relation to the approximate time markers represented by the coal seams and the floral zones, the lithostratigraphic change from a sandstone to an alternating assemblage occurred much earlier on the eastern side of the study area than on the western side. Once again, the mapping of this contact across the Basin must await data from inland exposures and boreholes.

The alternating assemblage represents deposition on a low-slope, low-energy alluvial plain, with relatively few, large, high sinuosity channels. This gave rise to relatively large areas on the floodplain on which mud was deposited; compaction caused water tables to be continuously high, so that swamp vegetation flourished. In general terms this explains why the thicker, more abundant coal seams occur in the alternating facies assemblage. The initiation of this facies assemblage earlier in the eastern part of the Basin indicates that gradients and energy levels decreased earlier there. An important factor which is not yet understood is why deposition of thicker and more abundant peat units did not commence with the initiation of the alternating assemblage in the east. A possibility is that other paleoecological factors, including paleoclimate could have controlled the spread of vegetation that gave rise to extensive peats in the *Ptychocarpus unitus* zone. It is hoped that further work on data already collected will allow this matter to be elucidated.

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LOCH LOMOND BASIN, CAPE BRETON ISLAND, WINDSOR GROUP PROJECT - AN UPDATE*

R. C. Boehner

INTRODUCTION

Field activities continued in the Loch Lomond Basin (Fig. 1) first outlined in a preliminary report by Boehner (1981). This outline summarized previous work and results up to the 1980 field season. Field mapping and logging of a series of diamond-drill hole controlled cross-sections has been completed in the area between Head of Loch Lomond and Terra Nova-Big Glen (Fig. 2). The project area is planned to be extended into the Salmon River area through to the southern part of the Sydney Basin project area (see Giles, this volume).

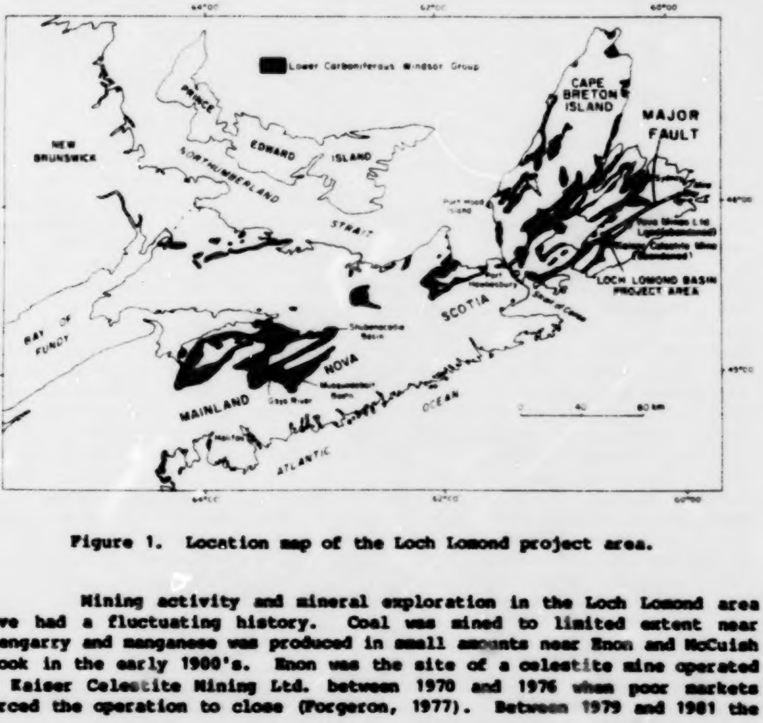
64°00
62°00
60°00
46°00
45°00
Lower Carboniferous Windsor Group
CAPE BRETON ISLAND
MAJOR FAULT
NEW BRUNSWICK
PRINCE EDWARD ISLAND
NORTHUMBERLAND STRAIT
Port Hood Island
Port Hawkesbury
Strait of Canso
LOCH LOMOND BASIN PROJECT AREA
BAY OF FUNDY
NOVA SCOTIA
MAINLAND
Shubenacadie Basin
Musquodoboit Basin
Gays River
Halifax
ATLANTIC OCEAN
0
40
80 km

Figure 1. Location map of the Loch Lomond project area.

Mining activity and mineral exploration in the Loch Lomond area have had a fluctuating history. Coal was mined to limited extent near Glengarry and manganese was produced in small amounts near Enon and McCuish Brook in the early 1900's. Enon was the site of a celestite mine operated by Kaiser Celestite Mining Ltd. between 1970 and 1976 when poor markets forced the operation to close (Forgeron, 1977). Between 1979 and 1981 the

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*Contribution to Canada-Nova Scotia Co-operative Mineral Program 1981-84 Project carried by Nova Scotia Department of Mines and Energy and by Geological Survey of Canada.

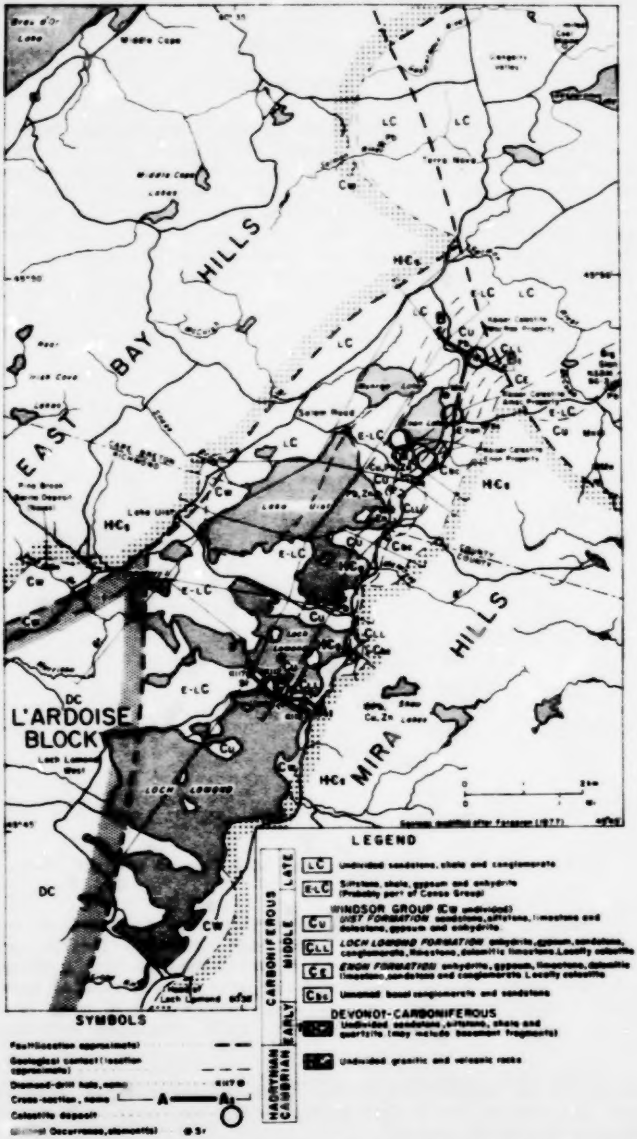
Bras d'Or Lake
Middle Cape
Middle Cape Lakes
Terra Nova
LC
E-LC
Cu
Cw
CLL
CE
Cbc
HCs
DC
Pb, Zn
Cu, Zn
EAST BAY HILLS
MIRA HILLS
L'ARDOISE BLOCK
Irish Cove
Salem Road
Loch Uist
Loch Lomond
LOCH LOMOND
Loch Lomond West
Enon Lake
Kaiser Celestite Enon Property
Kaiser Celestite Enon Property
Kaiser Celestite Enon Property
Shaw Lakes
0
2 km
0
1 mi
LEGEND
CARBONIFEROUS
LATE
MIDDLE
EARLY
HADRYNIAN CAMBRIAN
LC Undivided sandstone, shale and conglomerate
E-LC Siltstone, shale, gypsum and anhydrite (Probably part of Canso Group)
WINDSOR GROUP (Cw undivided)
Cu UIST FORMATION sandstone, siltstone, limestone and dolostone, gypsum and anhydrite
CLL LOCH LOMOND FORMATION anhydrite, gypsum, sandstone, conglomerate, limestone, dolomitic limestone. Locally celestite
CE ENON FORMATION anhydrite, gypsum, limestone, dolomitic limestone, sandstone and conglomerate. Locally celestite
Cbc Unnamed basal conglomerate and sandstone
DEVONO?-CARBONIFEROUS
Undivided sandstone, siltstone, shale and quartzite (may include basement fragments)
Undivided granitic and volcanic rocks
SYMBOLS
Fault (location approximate)
Geological contact (location approximate)
Diamond-drill hole, name
Cross-section, name
A
A1
Celestite deposit
Mineral Occurrence, element(s)
Sr

Figure 2. Preliminary geological map of the Locn Lomond Basin, Cape Breton Island.

mill at Enon was used by Yava Mines Ltd. to produce lead concentrate from the Salmon River lead deposit located 14 km to the northeast. Declining metal prices and difficult economic conditions were major contributors to the premature closing of the Yava Mine. More recently Novex Mining and Exploration Ltd. is reactivating the mill at Enon to beneficiate barite from the Pine Brook deposit on the northwestern border of the Loch Lomond Basin (Fig. 2).

The Loch Lomond Project was undertaken to document the stratigraphic onlap of Windsor Group rocks in an area of high paleotopographic relief in a marginal basin setting. Within this framework the distribution and origin of the area's numerous mineral occurrences and deposits (Sr, Ba, Pb, Cu, Zn, Mn and Fe) could be evaluated and predictive models developed. Economic minerals are believed to be closely related to paleogeography (topography), and sedimentation history especially unconformities and stratigraphic onlap-overstep. The possible inherited relationship of the geochemistry of the underlying basement to adjacent sediment hosted mineral deposits remains to be determined.

STRUCTURE

The Loch Lomond Basin is an asymmetric structural basin and contains up to 800+ m of Viséan to Namurian age rocks. It has the form of a northeasterly-southwesterly trending half graben bounded on the northwest by a high angle fault (Fig. 2). This fault is inferred to have up to 800 m of dip slip and uncertain, but potentially kilometres of strike slip. It is a major fault that extends from the Strait of Canso to Mira Bay (Figs. 1 and 2). The Basin is bordered on the northwest by Hadrynian Fourchu Group volcanic-sedimentary rocks and plutonic rocks of the East Bay Hills. The major unconformable contact to the southwest is with similar rocks of the East Bay Hills (largely the Loch Lomond pluton). To the southwest, the basin pattern is complicated by the L'Ardoise Block consisting of deformed Devono-Carboniferous sediments. This block although originally considered to be a thrust (Weeks, 1954) is presently interpreted to be bounded by high angle strike slip faults and is allochthonous to the area. The continuity of the northwestern border fault is broken by a high angle transverse fault near Terra Nova and Big Glen. Small scale faults (displacement <2 m) related to this fault are found in the MacRae property celestite open-pit.

Faulting which is suspected to occur locally along the southeastern border of the Basin has probably been obscured by solution collapse and the highly irregular basement topography. Present basement slopes, as interpolated from drillhole data range from 10°-15° in the intermediate to central part of the Basin to 20°-35° along parts of the margin. The steeper dips may be related to early basin block faulting and erosion.

STRATIGRAPHY AND SEDIMENTATION

The Loch Lomond Basin contains a mixed Carboniferous succession dominated by continental alluvial-fluvial and marine evaporite-carbonate sediments. The Carboniferous generally represents molassic deposition in a complex wrench fault basin system. The Loch Lomond Basin area is one of the few areas where data are available to document the details of progressive onlap of coarse and fine grained siliciclastics and carbonates onto basement. Major rock packages recognized (Fig. 3) are comparable (with a few exceptions) with those in other parts of Nova Scotia and include in ascending order: Windsor Group evaporite, fine to coarse redbeds and marine carbonate (middle and upper parts only), Enon, Loch Lomond and Uist Formations (up to 350 m); fine grained Canso Group (up to 200 m); and upper Canso Group (dominantly grey sandstone up to 250+ m).

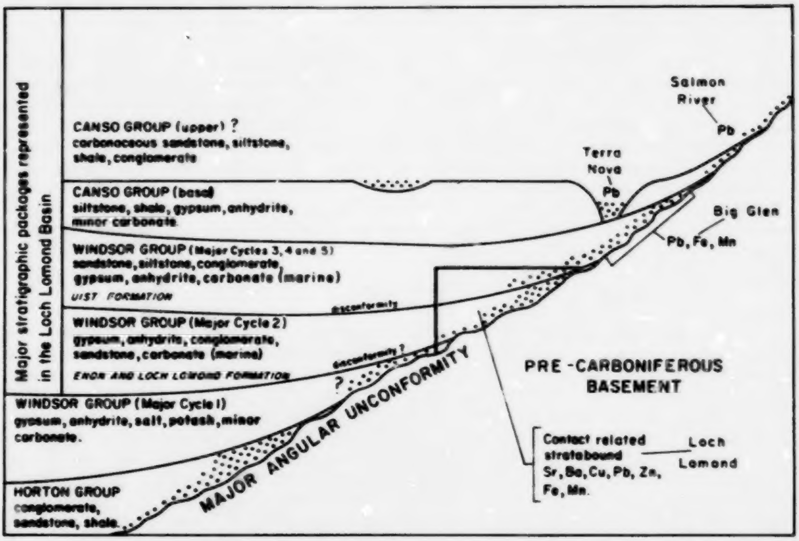
Major stratigraphic packages represented in the Loch Lomond Basin
CANSO GROUP (upper) ?
carbonaceous sandstone, siltstone, shale, conglomerate
CANSO GROUP (basal)
siltstone, shale, gypsum, anhydrite, minor carbonate
WINDSOR GROUP (Major Cycles 3, 4 and 5)
sandstone, siltstone, conglomerate, gypsum, anhydrite, carbonate (marine)
UIST FORMATION
disconformity
WINDSOR GROUP (Major Cycle 2)
gypsum, anhydrite, conglomerate, sandstone, carbonate (marine)
ENON AND LOCH LOMOND FORMATION
unconformity ?
?
WINDSOR GROUP (Major Cycle I)
gypsum, anhydrite, salt, potash, minor carbonate.
HORTON GROUP
conglomerate, sandstone, shale.
MAJOR ANGULAR UNCONFORMITY
PRE-CARBONIFEROUS BASEMENT
Salmon River
Pb
Terra Nova
Pb
Big Glen
Pb, Fe, Mn
Contact related stratabound Sr, Ba, Cu, Pb, Zn, Fe, Mn.
Loch Lomond

Figure 3. Schematic stratigraphy, onlap-overstep and mineral occurrences, Loch Lomond Basin and vicinity, Cape Breton Island.

Progressive onlap and overstep of stratigraphic packages with accompanying facies changes are well documented both parallel and perpendicular to the strike of the Loch Lomond Basin (Fig. 3). Similar changes are also present in the Salmon River-Glengarry Basin. Details of these features remain to be fully documented (1982-1983).

The typical basal Windsor Group evaporite section (Major Cycle 1) and Horton Group rocks are absent in the Loch Lomond Basin because of onlap and overstep (Fig. 3). Some of the coarse conglomerate breccia at the base of the section, especially in the Head of Loch Lomond area southwest to Grand River, may be a marginal fanglomerate facies of Major Cycle 1. Major Cycles 2 through 5 (subzone B and subzones C to E) display rapid facies variation, but are typical of mixed continental and evaporitic marine Windsor Group lithology. The Enon and Loch Lomond Formations (Major Cycle 2) are interstratified sections dominated by gypsum and anhydrite, with redbeds, conglomerate-breccia, sandstone, siltstone and fossiliferous marine carbonate. This package is disconformably overlain by the Uist Formation.

The Uist Formation (Major Cycle 3) is a generally similar package, but is dominated by redbeds, siltstone-sandstone and minor conglomerate with interbedded fossiliferous marine carbonate and minor gypsum and anhydrite.

Conformably overlying fine grained Canso Group rocks are dominantly grey and red siltstone-shale with minor gypsum and anhydrite, and rare algal limestone. This sequence is inferred to represent the transition from marine to continental sedimentation in residual evaporitic lacustrine environment that followed the retreat of Windsor seas. A thick fluvial section of grey sandstone with minor red to grey siltstone-shale concordantly to disconformably overlies the fine grained Canso and is tentatively assigned to the upper part of the Canso Group.

Windsor Group sections representing Major Cycles 2 through 5 (subzone B and subzones C to E) display rapid facies change ranging over a distance of several kilometres from evaporite dominated (ie. Passage Bridge Section, Fig. 4a) to terrigenous (conglomerate breccia) dominated (ie. MacRae Property, Fig. 4b). Marine carbonate members locally exhibit rapid facies change especially in the terrigenous dominated sections. In these sections the carbonate has undergone severe recrystallization, has been reworked to form calcirudites or has been completely removed by erosion. In some areas shelly carbonate banks are preferentially developed on, or surrounding, protruding paleotopographic basement highs. Facies change is particularly dramatic where redbeds change basinward to evaporites. This change is masked and complicated in part by karstification and solution collapse features.

Within the Windsor Group formations, the carbonate members pinchout marginally (Fig. 5). The major members record widespread and sustained marine invasions trangressing further up the margin of the basin. Thinner carbonate members representing less widespread marine transgressions pinchout and are not represented in areas such as Big Glen and Terra Nova. These areas which are structurally preserved by faulting, may represent facies which formerly were present updip (southeast) from the Loch Lomond area. A similar facies relationship may also be inferred to occur parallel to the basin strike (to the northeast).

Paleotopography and tectonism greatly influenced sedimentation in the Loch Lomond Basin especially in the early stratigraphic units. The importance of paleotopography decreased with time as erosion and deposition of onlapping strata buried the basement topography. The sequence to the top of the fine grained Canso Group displays overall fining upward and basinward trends. Coarse fanglomerates occur as marginal facies of the Windsor Group at all stratigraphic levels.

The Windsor Group has been complicated by karstification and solution collapse of subcropping evaporite sections along the southeastern border of the Basin (Fig. 4a). The age(s?) of this feature are as yet unclear, but appear to postdate the celestite deposits which are collapsed and redistributed to some extent. Diagenetic and weathering processes may have been important in the preparation of porosity-permeability within host rocks.

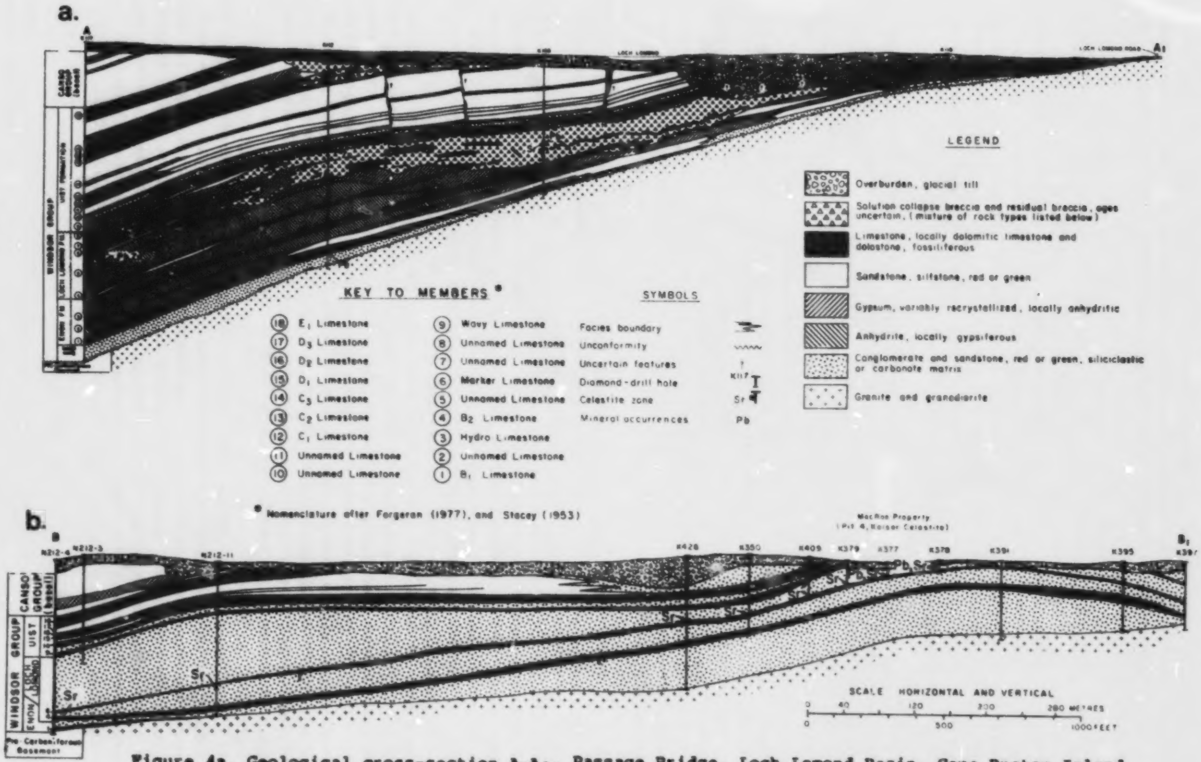
a.
A
A1
LOCH LOMOND
LOCH LOMOND ROAD
WINDSOR GROUP
CANSO GROUP (basal)
UIST FORMATION
LOCH LOMOND FM
ENON FM
LEGEND
Overburden, glacial till
Solution collapse breccia and residual breccia, ages uncertain, (mixture of rock types listed below)
Limestone, locally dolomitic limestone and dolostone, fossiliferous
Sandstone, siltstone, red or green
Gypsum, variably recrystallized, locally anhydritic
Anhydrite, locally gypsiferous
Conglomerate and sandstone, red or green, siliciclastic or carbonate matrix
Granite and granodiorite
KEY TO MEMBERS *
⑱ E₁ Limestone
⑰ D₃ Limestone
⑯ D₂ Limestone
⑮ D₁ Limestone
⑭ C₃ Limestone
⑬ C₂ Limestone
⑫ C₁ Limestone
⑪ Unnamed Limestone
⑩ Unnamed Limestone
⑨ Wavy Limestone
⑧ Unnamed Limestone
⑦ Unnamed Limestone
⑥ Marker Limestone
⑤ Unnamed Limestone
④ B₂ Limestone
③ Hydro Limestone
② Unnamed Limestone
① B₁ Limestone
SYMBOLS
Facies boundary
Unconformity
Uncertain features ?
Diamond-drill hole K11?
Celestite zone Sr
Mineral occurrences Pb
* Nomenclature after Forgeron (1977), and Stacey (1953)
b.
B
N212-4
N212-3
N212-11
K428
K350
K409
K379
K377
K378
K391
K395
K397
B1
MacRae Property (Pit 4, Kaiser Celestite)
Sr
Pb
CANSO GROUP (basal)
WINDSOR GROUP
UIST
LOCH LOMOND
ENON
Pre-Carboniferous Basement
SCALE HORIZONTAL AND VERTICAL
0 40 120 200 280 METRES
0 500 1000 FEET

Figure 4a. Geological cross-section A-A_1, Passage Bridge, Loch Lomond Basin, Cape Breton Island.
4b. Geological cross-section B-B_1, MacRae Property, Loch Lomond Basin, Cape Breton Island.

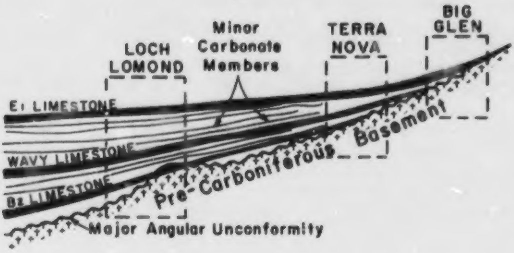

Figure 5. Windsor Group onlap relations in the vicinity of Loch Lomond, Terra Nova and Big Glen.

MINERAL DEPOSITS

Mineral development in the Loch Lomond Basin has occurred primarily in the celestite deposits at Lake Enon with very minor exploitation of manganese at McCuish Brook. Substantial celestite resources are presently economically unattractive due to lack of markets. Mineral exploration has been directed at base metal deposits of several types: 1) the Salmon River type, galena in sandstone, e.g. Terra Nova; 2) carbonate hosted onlap facies Pb-Zn similar to the Gays River type, e.g. E_1 limestone at Big Glen, B_2 limestone; and 3) contact oriented, Macumber Formation Horton-Windsor contact type Cu ± Pb ± Zn, e.g. B_1 limestone.

Base metals ± celestite ± Fe-Mn occurrences are contact related and localized at or near unconformity pinchouts at all stratigraphic levels (Fig. 3) where suitable chemistry, hydrology, lithology and geometry were present. Pinchout areas are inferred to have provided the necessary geometric conditions trapping and mixing metal-mineralizing fluids. Pyrite and/or organic material (coal debris and possibly liquid hydrocarbons) within a suitably porous and permeable host may have been important precipitating agents for base metals. However, the details of base metal deposition are unclear. The weathering for diagenetic alteration of silicate minerals in the continental sediments is a possible source of metals within tectonically active evaporitic arid molassic basins.

Tectonism, high angle faults and possibly increased thermal activity related to tectonism may have been important as the driving mechanism for large scale movement of mineralizing fluids.

Barite and celestite ± Pb ± Fe are dominantly stratabound, nodular to irregular replacement deposits. Carbonate rocks and redbeds are the major hosts. Celestite bodies are localized at or near facies changes particularly in carbonate rocks at carbonate-gypsum contacts and in redbeds at gypsum contacts. Sr is a common minor element in marine evaporites and may be released during gypsum/anhydrite dehydration/hydration. Shallow subaqueous and diagenetic nodular sulphates (modern sabkhas) often have celestite as an accessory mineral, but never in the large amounts present at Loch Lomond. Dissolution of Sr-enriched evaporites may be a source for Loch Lomond celestite, but a working hypothesis is yet to be tested. Dissolution of updip evaporites may have occurred during regression and redbed progradation (fanglomerate) may have provided a preconcentrated source for a large quantity of strontium. This could have migrated downdip in continental waters within the redbeds. Deposition of celestite from solutions subsequently occurred as replacement of suitable (sulphate enriched) host redbeds and carbonate. Base metals, especially Pb, are sometimes closely associated with the celestite. Fe may also be present as hematite especially in redbed hosts. Barite and celestite ± Pb ± Fe may represent early diagenetic replacement during, or soon after sedimentation.

Barite occurs as replacement of limestone in a stratabound deposit at Pine Brook (Fig. 2). Although details of the setting and origin of this deposit are not clear it appears to be similar in character to the celestite bodies at Enon.

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MEGUMA GOLD PROJECT,

THE COUNTRY HARBOUR AREA, GUYSBOROUGH COUNTY, NOVA SCOTIA*

J. D. Keppie, S. J. Haynes, G. K. Muecke**, B. H. O'Brien, P. K. Smith

and

J. W. F. Waldron***

This project is part of the Canada-Nova Scotia Co-operative Mineral Program 1981-84. It is a multidisciplinary study involving conceptual mapping of the area followed by various specialist studies. The area (Fig. 1) was selected on the basis of recent mapping by McBride (1978) and Smith (1981) and problems identified during Province-wide surveys (Keppie, 1979, 1982; Chatterjee, 1983). B. H. O'Brien and J. D. Keppie continued the mapping followed by detailed structural and metamorphic studies. During 1982 mapping was undertaken mainly in the southern half of the area and preliminary reports of the field work follow. G. K. Muecke has started a study of the metamorphic history and the phase chemistry of the metamorphic minerals. S. J. Haynes and P. K. Smith have been mainly involved with the metallogeny of the auriferous mineral occurrences in the area, and preliminary results of the field component of this work are included here.

J. W. F. Waldron has started a sedimentological study of the Goldenville Formation. R. D. Dallmeyer, A. H. Halliday and R. F. Cormier have begun geochronological studies in the area. B. Chevalier is doing a B.Sc. honours thesis on the Bull Ridge pluton. The Geological Survey of Canada will undertake an airborne gradiometer/VLF-EM (Hertz Industries BTRZ Totem 2A) survey of the area in 1983.

The adjacent area to the west, between 62°00' and 62°30', is being mapped by J. R. Henderson of the Geological Survey of Canada with V. Kretschmar studying the economic geology and arsenopyrite-gold relations and J. Crocket, P. Clifford and students studying the gold geochemistry and structural geology of selected areas. This study also included a pilot ground gradiometric study and a till geochemical dispersal study around several gold districts.

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*Contribution to Canada-Nova Scotia Co-operative Mineral Program 1981-84. Project carried by Nova Scotia Department of Mines and Energy and by Geological Survey of Canada.

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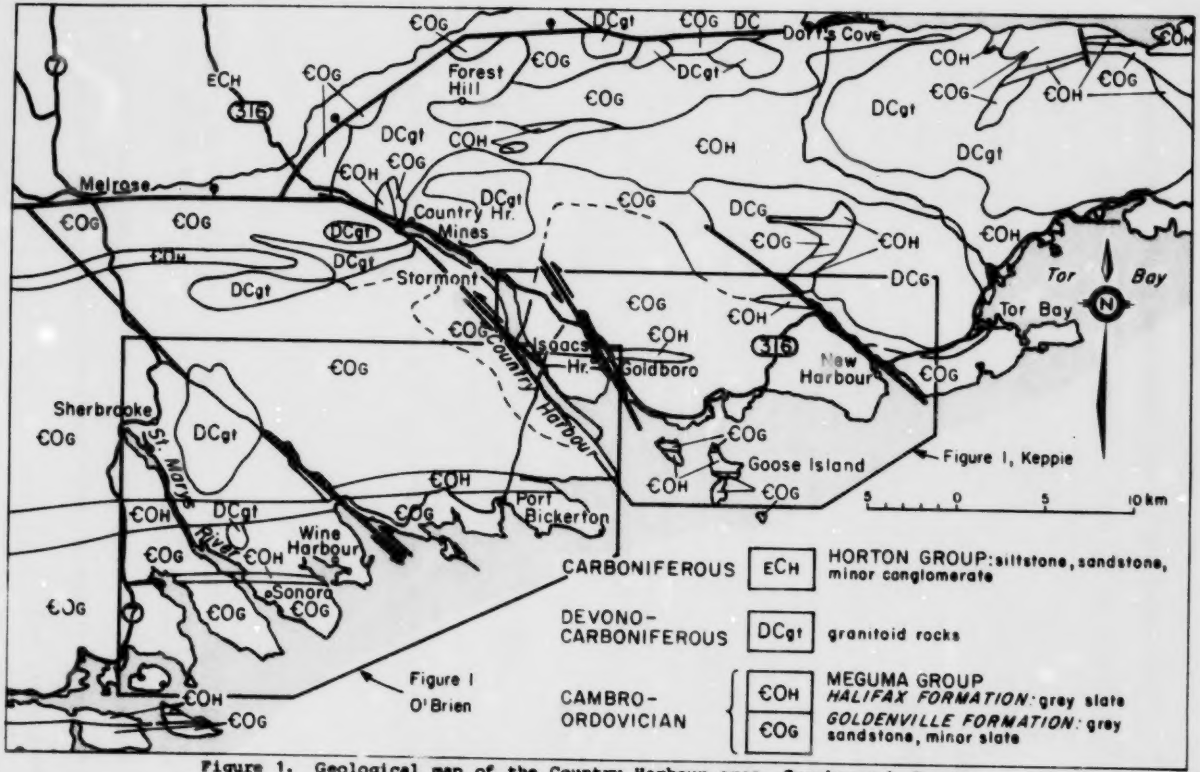
ЄOG
DCgt
ЄOG
DC
Dorr's Cove
ЄOH
ECH
316
Forest Hill
DCgt
ЄOG
COH
ЄOG
ЄOH
ЄOG
COH
DCgt
Melrose
DCgt
Country Hr. Mines
ЄOG
DCG
ЄOG
ЄOH
DCgt
ЄOH
DCgt
Stormont
DCG
Tor
Bay
Tor Bay
N
ЄOG
ЄOH
Isaacs Hr.
Goldboro
New Harbour
Country Harbour
Sherbrooke
St. Marys River
Goose Island
Figure 1, Keppie
Port Bickerton
Wine Harbour
Sonora
Figure I O'Brien
5
0
5
10 km
CARBONIFEROUS
ECH
HORTON GROUP: siltstone, sandstone, minor conglomerate
DEVONO-CARBONIFEROUS
DCgt
granitoid rocks
CAMBRO-ORDOVICIAN
ЄOH
ЄOG
MEGUMA GROUP
HALIFAX FORMATION: grey slate
GOLDENVILLE FORMATION: grey sandstone, minor slate

Figure 1. Geological map of the Country Harbour area, Guysborough County, Nova Scotia (modified from Keppie, 1979).

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GEOLOGICAL HISTORY OF THE ISAACS HARBOUR AREA

PARTS OF 11F/3 AND 11F/4, GUYSBOROUGH COUNTY, NOVA SCOTIA*

J. D. Keppie

ABSTRACT

The Meguma Group of the Isaacs Harbour area consists of the predominantly sandy turbidites of the Goldvenville Formation overlain by slates of the Halifax Formation. Deposition of the Meguma Group appears to have been accompanied by the formation of monoclinal faults over postulated high angle basement faults. These faults are believed to have formed in response to the transpression which produced the graben or trough in which the Goldenville Formation was deposited. These faulted monoclines also appear to have formed the locus of fissures which formed the conduits for hot springs producing auriferous veins.

Deposition of the Meguma Group was followed by three phases of (?)Acadian deformation accompanied by greenschist facies metamorphism. The first, D_s, produced a low angle foliation induced by mass sliding on bedding plane shears. The second and main phase of deformation, D_g, produced the major folds, pressure solution and slaty cleavage. These F_g folds appear to have nucleated at the steep limbs of the early monoclinal folds. Gold appears to have been remobilized into tight cylindrical and conical F_g fold hinges. The F_g folds were produced by oblique flexural folding and tangential longitudinal strain with the X-axis of the finite strain ellipsoid approximately horizontal and east-west. It is postulated that these structures were induced by dextral transcurrent movements on the faulted monoclines. This is consistent with the dextral movements inferred to have taken place on the Minas Geofracture during the Acadian Orogeny. The third phase of deformation, D_c, produced a subhorizontal crenulation cleavage as a result of gravitational collapse induced by the relaxation of the D_g stresses.

This was closely followed by amphibolite facies, low pressure regional metamorphism in the northern part of the area, characterized by porphyroblasts of biotite, garnet, staurolite, andalusite and cordierite. This was followed by intrusion of the Sherbrooke pluton yielding a whole rock Rb/Sr isochron age of 369 ± 2 Ma.

Further deformation followed correlated with the Hercynian Orogeny. This produced shear and flattening foliations which transposed earlier fabrics and rotated the porphyroblasts which are most intense north of the Stormont and Waternish Synclines. Gold appears to have been remobilized along Hercynian shear zones. This deformation becomes less intense southwards. Kinematic interpretation suggests that these structures resulted from dextral movements on the Minas Geofracture.

Finally, the area was cut by a series of northwest-southeast sinistral transcurrent faults associated with kink bands. These are

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*Contribution to Canada-Nova Scotia Co-operative Mineral Program 1981-84. Project carried by Nova Scotia Department of Mines and Energy and by Geological Survey of Canada.

inferred to be the result of sinistral movements on the Minas Geofracture during the early Mesozoic as the Bay of Fundy Rift formed.

STRATIGRAPHY

The area mapped during the 1982 field season (Fig. 1) is underlain by rocks of the Cambro-Ordovician Meguma Group divisible into the Goldenville Formation overlain by the Halifax Formation.

Goldenville Formation

The Goldenville Formation is mainly made up of sandstones interbedded with thin slate horizons, which are inferred to have been deposited by turbidity currents and reworked by bottom currents (Schenk, 1970; Harris, 1971; Waldron, this volume). Individual sandstone beds range in thickness from about 1 cm up to several metres and display a variety of Bouma sequences ranging from the complete a-e sequence to attenuated "a" or c/e units. The sandstone beds usually have erosional bases displaying flutes and grooves which are extensively modified where the pressure solution cleavage is strongly developed to the point where it is often difficult to distinguish the primary from secondary effects (Fig. 2). Where the distinction is possible current directions derived from flute casts have a west-to-east subhorizontal orientation (cf. Schenk, 1970; Harris, 1971; Waldron, this volume). Internal sedimentary structures include grading, parallel-, cross- and convolute-lamination. Pipe and sheet structures, composed of higher quartz content than the enclosing sandstone may often be observed towards the top of sandstone beds often terminating upwards in sand volcanoes on the upper bedding surface. Deformed ripples are occasionally present on the upper bedding surface also. In some cases, the upper surface of sandstone beds has an erosional surface, and where the overlying unit is sandstone it produces an amalgamated sandstone unit. Where the overlying unit is shale, reworking of the sandstone bed by bottom currents is inferred (Waldron, this volume). The interbedded slate units often contain sandstone dykes which can easily be mistaken for bedding where they have been rotated into subparallelism with the bedding during subsequent deformation.

The Goldenville Formation is at least 2 km thick in the Isaacs Harbour area, however it reaches at least 8 km thick elsewhere in the Meguma Terrane. The possibility of subdividing the Goldenville Formation was examined, and although it is possible to separate predominantly massive sandstone units from interbedded sandstone and slate units in continuously exposed coastal sections, it is generally impossible to trace these units in the usually poorly exposed inland areas. Even in the area west of New Harbour where till cover is thin and individual sandstone units may be traced as ridges (Fig. 3) it is still impossible to make any meaningful stratigraphic subdivision. The upper part of the Goldenville Formation is usually represented by a thin transition zone of thinly bedded sandstones and slates. In this context, it is encouraging to know that high resolution aeromagnetic vertical gradient maps in the Yarmouth and Halifax areas (Anonymous, 1982) outline linear bands of anomalies which have been correlated with massive sandstone units (Chatterjee and Keppie, 1981; Waldron, this volume). Examination of these sandstone units in this area indicates that magnetite is one of the opaque minerals which could be the cause of the magnetic anomalies in the Goldenville Formation, as was found to be the case in the Halifax and Yarmouth areas (McGrath, 1970; Chatterjee and Keppie, 1981). It remains to be determined whether the magnetite is detrital or metamorphic. Nevertheless, it appears that gradiometer technique offers the best chance for analyzing the three dimensional geometry and stratigraphy of the relatively intractable Goldenville Formation in the greenschist facies areas (Keppie and Muecke, 1979). Unfortunately, in the amphibolite facies, the linear bands of magnetic anomalies related to stratigraphic horizons disappear (Keppie et al., 1979). Also magnetite forms in the contact aureole of some of the granitoid plutons producing an associated magnetic anomaly (Anonymous, 1982; McGrath, 1970). Thus, other techniques will have to be employed in these higher grade areas.

Halifax Formation

The Halifax Formation is remarkably poorly exposed in the Isaacs Harbour area outcropping at only three localities on either side of Isaacs Harbour and on Goose Island. The slates are typically black, but are green in places at the base. In Isaacs Harbour, coarser material is generally lacking, however on Goose Island thin layers of sandstone displaying starved ripples occur interbedded with the slates. The Halifax Formation may be traced by its large positive magnetic anomaly caused by the presence of pyrrhotite which is visible in hand specimens (McGrath, 1970). Elsewhere in the Country Harbour area and in the Halifax area it is clear that the slates of the Halifax Formation vary in composition from ferruginous/manganiferous with visible pyrite and pyrrhotite, to aluminous. These variations may also be picked out on the vertical gradient magnetic anomaly maps (Anonymous, 1982).

STRUCTURE AND METAMORPHISM

Syn-Depositional Structures

Deposition of the Meguma Group appears to have been accompanied by movements on generally highly inclined east-west faults, which produced monoclinal folds. An example of these structures occurs between the North Syncline and North Anticline at Isaacs Harbour (Fig. 4). Here it is not possible to correlate individual beds across the fault inferred along the steep limb of the monocline between the Anticline and Syncline. Preliminary observations suggest that the monocline is pre-D_s because the S_s foliation cuts across the monoclinal fold hinge. A quartz vein intruded along this faulted monoclinal limb has been mined out. While later movements are inferred to have taken place on this fault its initiation may be inferred by reference to the age of the early stratabound and auriferous stratiform veins and their feeder step veins (Haynes, this volume). These veins can be shown to predate or to be synchronous with the earliest foliation, S_s, and associated folds, because they are deformed by them. However, 120 m north of the North Anticline a quartz-K-feldspar step vein feeds and terminates in a stratifrom quartz-chlorite-carbonate vein (Fig. 5). The stratiform vein is only present to the east of the junction with the step vein. These observations may be interpreted in terms of a cross-cutting vein reaching the ocean floor and pouring out on the ocean floor in a direction controlled by the prevailing bottom currents (Haynes, this volume). Bottom currents deduced from bottom structures such as flute casts on beds in this immediate locality show a west-east, subhorizontal

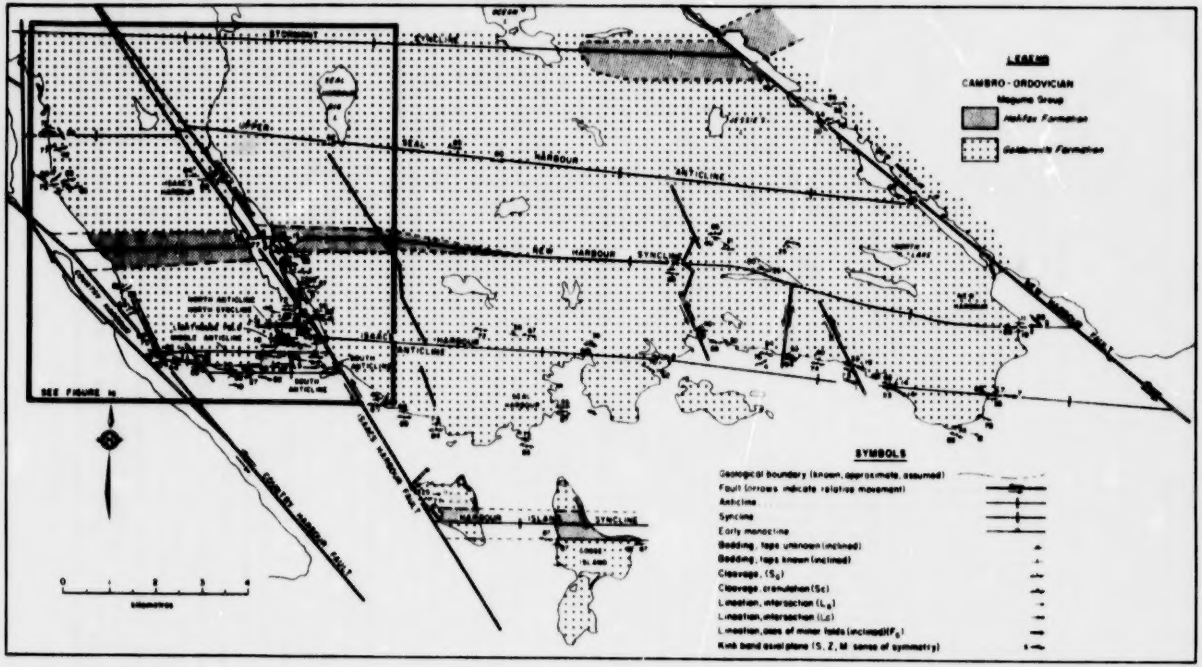

LEGEND
CAMBRO - ORDOVICIAN
Meguma Group
Halifax Formation
Goldenville Formation
SYMBOLS
Geological boundary (known, approximate, assumed)
Fault (arrows indicate relative movement)
Anticline
Syncline
Early monocline
Bedding, tops unknown (inclined)
Bedding, tops known (inclined)
Cleavage, (S1)
Cleavage, crenulation (Sc)
Lineation, intersection (L1)
Lineation, intersection (Lc)
Lineation, axes of minor folds (inclined)(F1)
Kink band axial plane (S, Z, M sense of symmetry)
STORMONT SYNCLINE
SEAL HARBOUR ANTICLINE
NEW HARBOUR SYNCLINE
ISAACS HARBOUR ANTICLINE
ISAACS HARBOUR FAULT
COUNTRY HARBOUR FAULT
NORTH ANTICLINE
NORTH SYNCLINE
MIDDLE ANTICLINE
SOUTH ANTICLINE
UPPER
SEAL
ISAAC'S HARBOUR
SEAL HARBOUR
COBBS ISLAND
HARBOUR
ISLAND
SYNCLINE
SEE FIGURE 1a
0
1
2
3
4
kilometres

Figure 1. Geological map of the Isaacs Harbour area. For location see Keppie et al., this volume (Meguma Gold Project, Fig. 1).

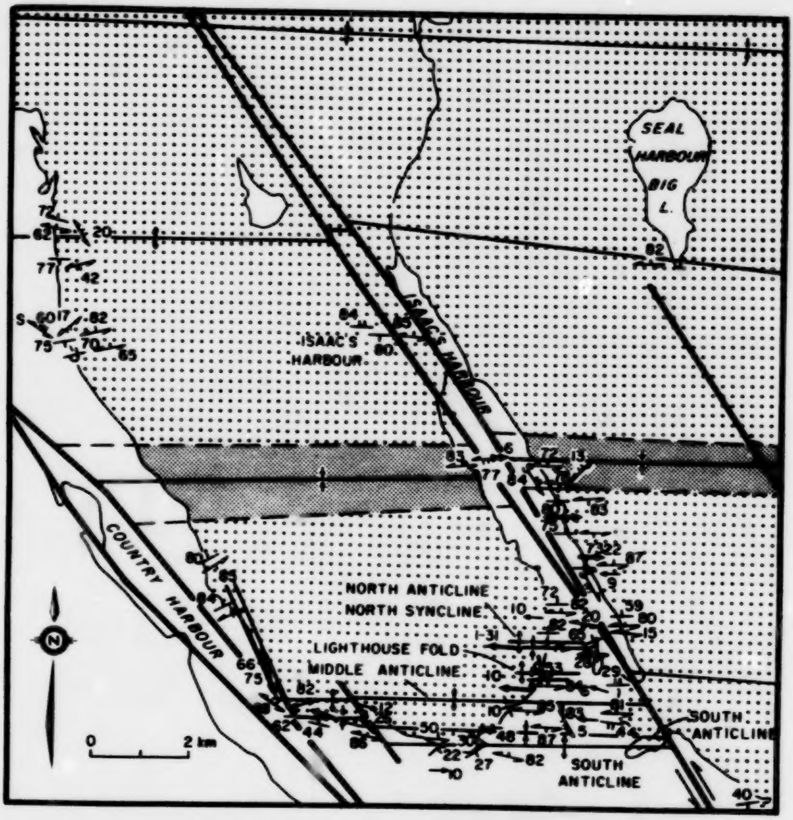

SEAL
HARBOUR
BIG
L.
ISAAC'S HARBOUR
ISAAC'S
HARBOUR
COUNTRY HARBOUR
NORTH ANTICLINE
NORTH SYNCLINE
LIGHTHOUSE FOLD
MIDDLE ANTICLINE
SOUTH ANTICLINE
SOUTH
ANTICLINE
N
0
2 km

Figure 1a. See Figure 1 for location.

orientation. Differences in the mineralogy of the step and stratiform veins are attributed to the different physico-chemical conditions below and on the ocean floor respectively (Haynes, this volume). This evidence suggests that at least some of the veins are synchronous with the deposition of the Goldenville Formation. The main feeders for these veins are inferred to be located along the faulted steep limbs of the monoclinal folds, such as the one located between the North Anticline and North Syncline.

Several monoclinal folds trending obliquely to the regional east-west trend have also been observed in the Isaacs Harbour area. One occurs about 100 m north of Isaacs Harbour lighthouse (Fig. 6) and another occurs on the northern end of Hurricane Island. In both of these cases,

Figure 2. Pseudoflutes and pseudogrooves on the base of a sandstone bed formed by the modification of primary irregularities by pressure solution cleavage, S_g.

the monoclinal fold is most clearly visible in the curvilinear bedding/S_g cleavage intersection lineations. Preliminary observations suggest that the lighthouse monocline is also pre-D_s. Field measurements show that the curvilinear pattern of lineations is probably not due to inhomogeneous syn-D_g deformation or conical F_g folds, but rather it is due to a pre-existing fold being cut by later S_g cleavage. The two and three dimensional shape of these early monoclinal folds requires the preparation of isogonic maps (Elliott, 1965) and must await further field work.

Major monoclinal folds, somewhat modified by later structures, may be observed elsewhere in the Meguma Terrane especially by reference to the cross-sections on the Faribault maps. These monoclines appear to have formed the locus for many of the later structures especially major folds, presumably due to the inhomogeneity they represent. This explains the common association of auriferous stratiform-stratabound veins with the major folds (Malcolm, 1929; Keppie, 1976). Where the stratiform-stratabound veins were intruded into the sediment as sills one could expect the veins to be equally distributed on both sides of the folds (e.g. Goldenville gold deposit). However, where the stratiform veins were produced as chemical deposits on the ocean floor, the bottom currents would control their distribution which in the general case would not be symmetrically distributed about the fold, as is observed in the Goldboro and Wine Harbour Gold Districts.

D_s Structures (?Acadian)

The earliest foliation recorded to date in the Meguma Group is named S_s after Sherbrooke where it was first discovered and is best

Figure 3. Aerial photograph of the area west of New Harbour where individual sandstone units may be traced as exposed ridges.

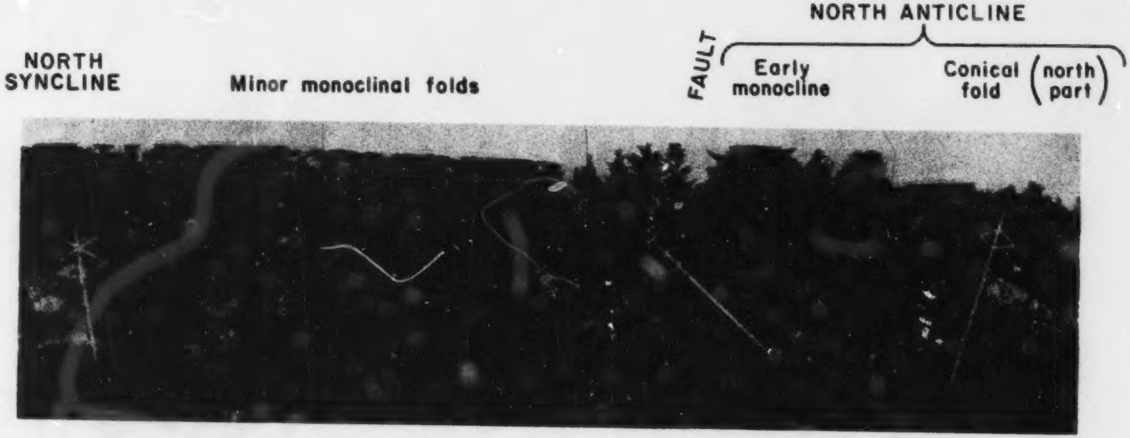

NORTH SYNCLINE
Minor monoclinal folds
FAULT
NORTH ANTICLINE
Early monocline
Conical fold
(north part)

Figure 4. Photograph of the North Anticline and North Syncline, Isaacs Harbour. The North Anticline is a composite box fold: the northern part is a conical F_g fold, and the southern part is an early monocline with a faulted steep limb. Minor monoclinal folds occur between the North Anticline and the North Syncline.

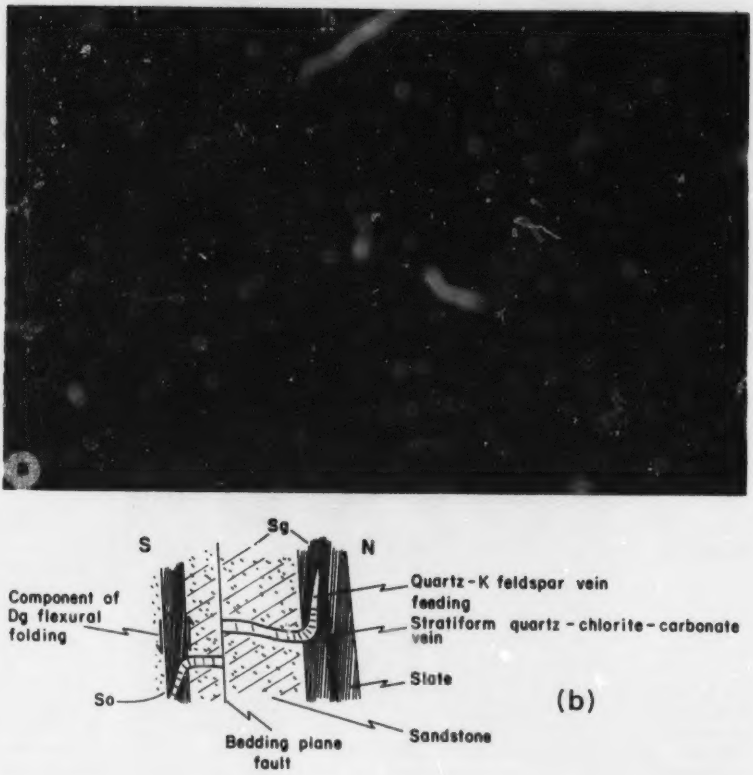

S
Sg
N
Component of Dg flexural folding
So
Bedding plane fault
Quartz - K feldspar vein feeding
Stratiform quartz - chlorite - carbonate vein
Slate
Sandstone
(b)

Figure 5. (a and b) Photograph and sketch of a quartz-K-feldspar step vein feeding an early quartz-chlorite-carbonate stratiform vein, ca. 120 m north of the North Anticline, Isaacs Harbour. The step vein generally has a shallow dip in the sandstone beds and a steep dip in the slates due partly to flexural folding deformation during Dg phase of deformation.

preserved (O'Brien, this volume). This foliation is typically expressed by a grain alignment cleavage, S_g, defined by muscovite and biotite in the Isaacs Harbour area. This cleavage is generally subparallel to the bedding in the pelitic layers but has a variable orientation in the psammite layers, due in part to subsequent deformation. Minor folds, F_g, associated with this cleavage are rare, and are best preserved in the early stratiform quartz veins (Fig. 7a), where they are generally asymmetrical with variable orientations. Orientations of fold axes vary from gently plunging east-west to steeply plunging. Many of these quartz veins also possess a strong linear fabric oriented at small angles to the stratiform

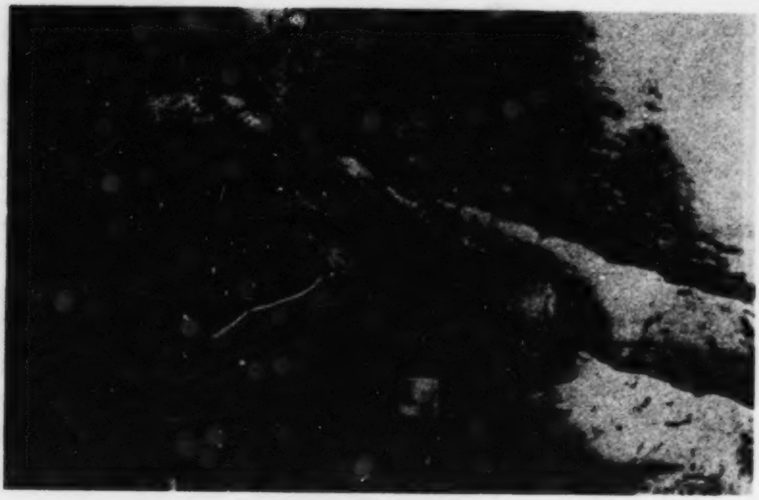


Figure 6. Photograph of (?)early monoclinal fold modified by later F_g fold ca. 100 m north of Isaacs Harbour Lighthouse dissected by S_g cleavage producing a curvilinear intersection lineation pattern, L_g (traced on photo).

vein walls and defined by elongate quartz crystals (Fig. 7b) which in some localities may be shown to be parallel to the F_s fold axes. These quartz crystals are inferred to be the result of syntectonic growth of crystal fibres (Durney and Ramsay, 1973), thus suggesting that the incremental extension directions were inclined at small angles to the bedding. It is proposed that the bedding planes acted as the planes of shear (Fig. 7c) (O'Brien, this volume) which explains the dirth of associated mesoscopic F_s folds in the Meguma Group rocks. From these minor structures one might predict the presence of major bedding plane thrusts and possibly recumbent folds, however, none have been identified to date. Thus, the magnitude of the structures associated with the D_s phase of deformation is at present uncertain. The age of these structures is at present unknown, however, they may have formed just prior to or at an early stage in the development of the D_g structures because both used the bedding as shear planes (see below).

The D_s structures are probably correlatives of the F_s structures recorded elsewhere in the Meguma Group which Keppie (1977) related to folding and thrusting during greenschist facies metamorphism. Subsequently some of these structures were thought to be due to loading (Keppie, 1982b) however, the present study suggests that they result from shear on the bedding planes with strain being most intense in the pelitic layers (O'Brien, this volume).

Figure 7a. Photograph of early stratiform vein deformed by both minor F_s and F_g folds with associated cleavages S_s and S_g. The stratiform vein feeds or is fed by a vein approximately parallel to the S_g slaty cleavage. This latter vein is planar or shows some pinch-and-swell and boundinage in this cross-section.

D_g Structures (Acadian)

The D_s phase of deformation was followed by the main phase of Acadian deformation, D_g, named after Guysborough County where the folds are widespread. The D_g phase of deformation includes the development of the major folds, multistage development of pressure solution cleavage and slaty cleavage, intersection, shape and mineral lineations. A remarkable feature of this phase of deformation is nonparallelism of the various D_g structures, with parallelism representing a special case. The early monoclinal (?faulted) folds also exerted a strong control on the location of many of the major F_g folds. These two factors have an important bearing on the genetic model inferred for the Dg structures.

Figure 7b. Photograph of early stratiform vein with L_s lineations defined by elongate quartz crystals deformed by F_g folds (photo by S. J. Haynes).

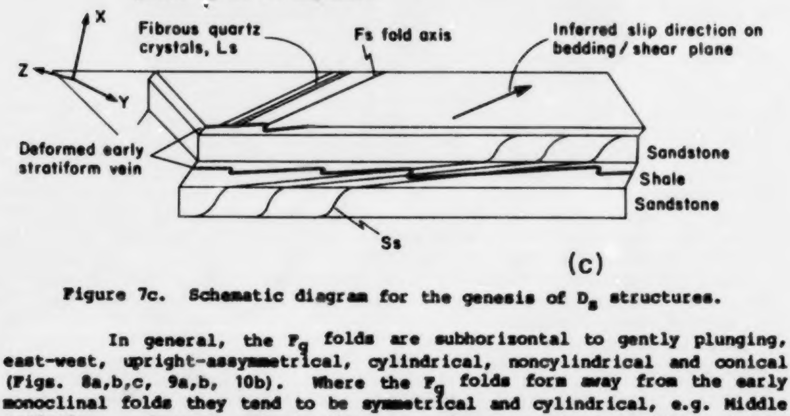

X
Z
Y
Fibrous quartz crystals, Ls
Fs fold axis
Inferred slip direction on bedding / shear plane
Deformed early stratiform vein
Sandstone
Shale
Sandstone
Ss
(c)

Figure 7c. Schematic diagram for the genesis of D_s structures.

In general, the F_g folds are subhorizontal to gently plunging, east-west, upright-assymmetrical, cylindrical, noncylindrical and conical (Figs. 8a,b,c, 9a,b, 10b). Where the F_g folds form away from the early monoclinal folds they tend to be symmetrical and cylindrical, e.g. Middle Anticline. However, where they are close to the monoclinal folds, noncylindrical and conical folds tend to develop, e.g. northern part of the North Anticline (Fig. 9a,b). The conical folds display some geometrical features that allow them to be recognized in the field without plotting the data on a stereonet. Thus where the associated cleavage is planar and parallel or slightly fanned, the bedding/cleavage intersection lineations are linear and gently plunging in the hinge and are curvilinear and gently to moderately plunging in the limbs (Fig. 9a-f). Field data compare well

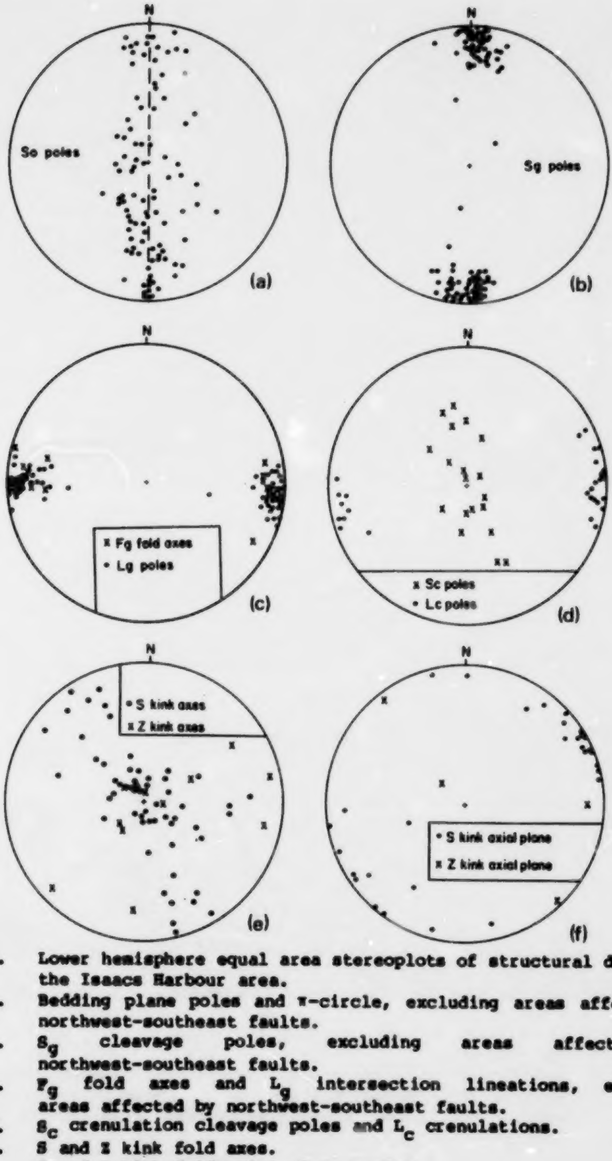


Figure 8. **Lower hemisphere equal area stereoplots of structural data from the Isaacs Harbour area.**

- **a.** **Bedding plane poles and π-circle, excluding areas affected by northwest-southeast faults.**
- **b.** **S_g cleavage poles, excluding areas affected by northwest-southeast faults.**
- **c.** **F_g fold axes and L_g intersection lineations, excluding areas affected by northwest-southeast faults.**
- **d.** **S_c crenulation cleavage poles and L_c crenulations.**
- **e.** **S and Z kink fold axes.**
- **f.** **S and Z kink fold axial planes poles.**

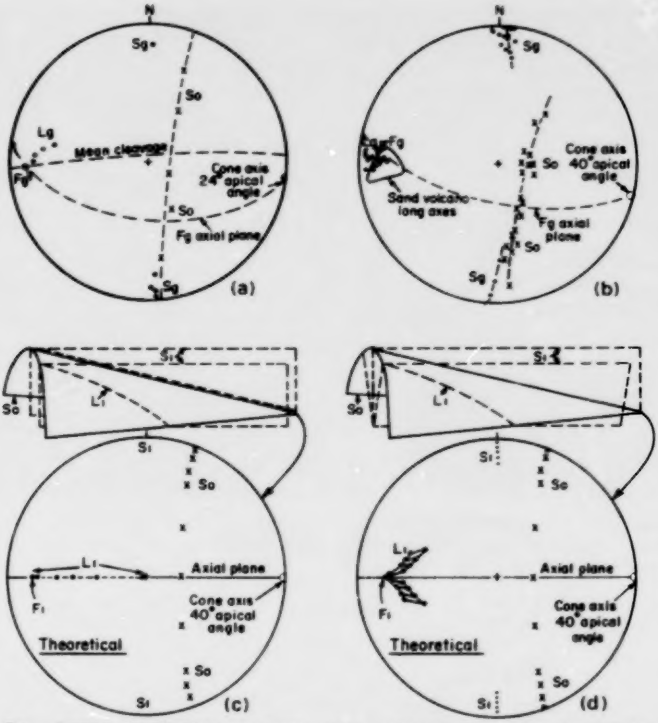

N
Sg
So
Lg
Mean cleavage
Fg
Cone axis
24° apical angle
So
Fg axial plane
Sg
(a)
N
Sg
Fg
So
Cone axis
40° apical angle
Sand volcano long axes
Fg axial plane
So
Sg
(b)
S1
So
L1
S1
So
Axial plane
L1
F1
Cone axis
40° apical angle
Theoretical
So
S1
(c)
S1
So
L1
S1
So
Axial plane
L1
F1
Cone axis
40° apical angle
Theoretical
So
S1
(d)

Figure 9a. Lower hemisphere equal area stereoplot of structural data from minor conical F_g fold just north of North Anticline, Isaacs Harbour. Bedding plane poles, S_o define a small circle with a cone apical angle of 24°. Slaty cleavage, S_g displays a slight fan and the bedding/cleavage intersection lineations, L_g, are curvilinear.

b. Stereoplot of northern half of the F_g North Anticline, Isaacs Harbour (Fig. 4) showing bedding plane poles, S_o, defining a small circle with a cone apical angle of 40°, fanned pressure solution cleavage poles S_g, bedding/cleavage intersection lineations L_g, and the field of the long axes of sand volcanoes .

c. Sketch and stereoplot of theoretical conical fold showing bedding plane poles, S_o, and planar S_1 cleavage producing curvilinear L_1 intersection lineation pattern in the plane of the cleavage.

d. Sketch and stereoplot of theoretical conical fold showing bedding plane poles S_o, and an S_1 cleavage fan producing a complex curvilinear S_1 bedding/cleavage intersection lineation pattern.

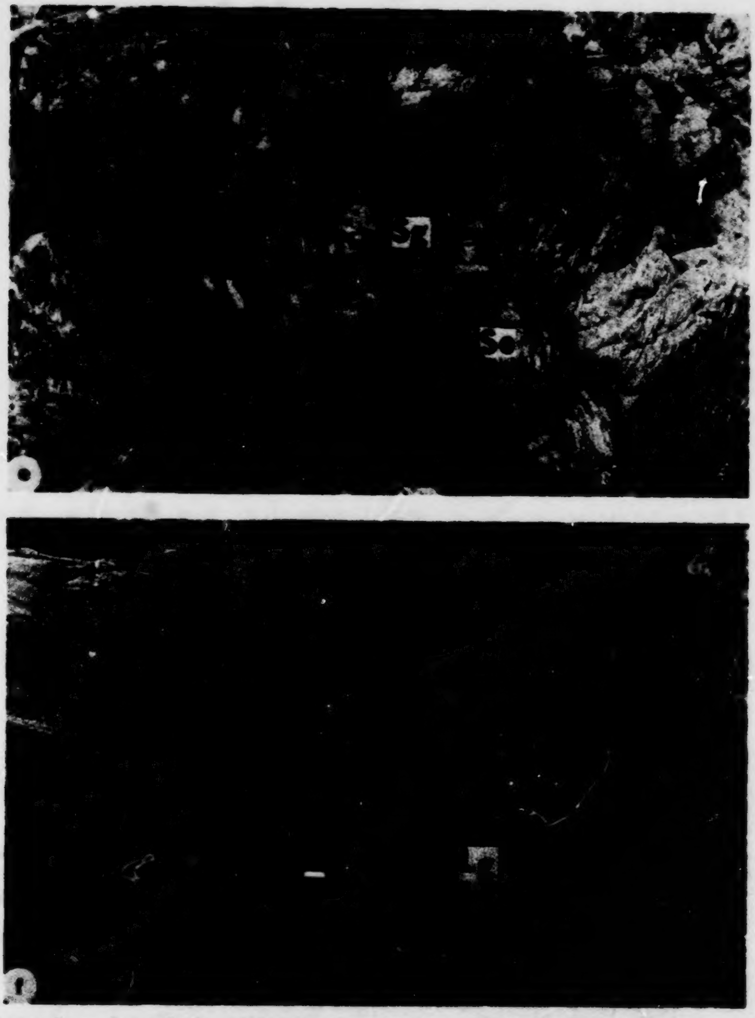


Figure 9. (e and f) Photographs of minor conical fold just north of North Anticline showing (e) cross-section and (f) curvilinear to linear bedding/cleavage intersection lineations, L_9, on S_9 slaty cleavage. Structural data plotted in Fig. 9a.

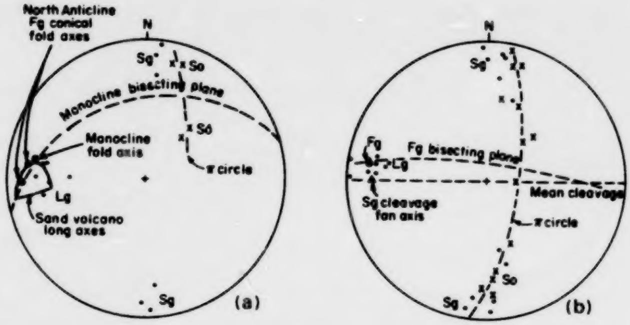


Figure 10a. Stereoplot of early faulted monoclinal fold modified by D_g structures forming southern half of North Anticline, Isaacs Harbour (Fig. 4). Cylindrical monocline outlined by bedding plane poles, S_o, with axial plane oblique to (i) S_g pressure solution and slaty cleavage, (ii) S_o/S_g intersection lineations, L_g, (iii) long axes of sand volcanoes, and (iv) conical F_g fold of northern part of North Anticline.

b. Stereoplot of structural data from North Syncline, Isaacs Harbour (Fig. 4) showing cylindrical F_g fold of bedding plane poles, S_o, and slightly oblique pressure solution cleavage S_g and bedding/cleavage intersection lineations, L_g.

with theroetical data (compare Fig. 9a and d). The conical folds appear to form where a fold terminates along its fold axis either now or at some stage during the fold development. Thus, the conical northern part of the North Anticline terminates at the early faulted monocline (Fig. 11a). The minor conical fold on the northern limb of the North Anticline (Fig. 9a,e,f) terminates where a facies change from pelitic to psammitic rocks occurs. Conical folds would be expected to occur where folds form in an en echelon oblique arrangement over a pre-existing fault due to strike-slip movements (Campbell, 1958; Badgley, 1965). This appears to be the case for both the minor conical fold described above and the F_g conical fold forming the northern part of the North Anticline. They are both oblique 10° to 20° in an anticlockwise sense to the early faulted monoclinal fold (Figs. 9a,b, 10a, 11a). Thus it is inferred that these en echelon conical folds formed as a consequence of dextral movements on the faulted steep limb of the early monoclinal fold. With progressive dextral shear strain, the en echelon folds would tend to be rotated towards the shear or fault plane. In the poorly exposed inland areas, the en echelon arrangement of the folds would probably be overlooked and instead mapped as one continuous linear fold trace (Fig. 11b). However, careful analysis of fold geometries around Halifax reveals that conical folds are common in the Meguma Terrane (Keppie, 1976).

A puzzling feature of the D_g phase of deformation is the general absence of minor F_g folds in the sandstones and shales of the Goldenville Formation. An exception to this rule is the early quartz veins

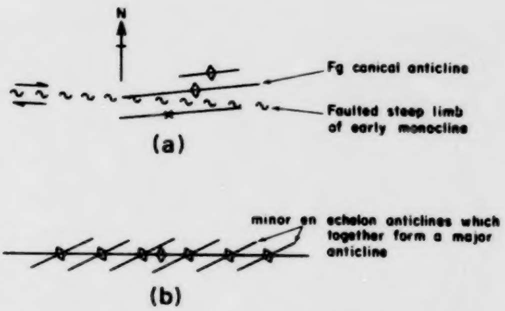

N
Fg conical anticline
Faulted steep limb of early monocline
(a)
minor en echelon anticlines which together form a major anticline
(b)

Figure 11a. Plan view of F_g conical folds and early faulted monoclinal fold at North Anticline, Isaacs Harbour, showing genetic model for oblique conical folds produced by dextral shear movements on the faulted steep limb of the monoclinal fold.

b. Zone of en echelon anticlines which together form a generally linear major fold.

which display numerous minor F_g folds (Fig. 7), and one would expect minor folds in the Goldenville Formation if it acted as a multilayer with layers of contrasting viscosities. This suggests that perhaps there was no competency difference between the sandstones and shales. This might be possible if pore water was trapped in the sandstone layers reducing their viscosity to that of the interbedded shales. However, this seems unlikely because the D_g deformation took place under greenschist facies conditions which would have driven off any pore water. An alternative explanation may be that some of the F_g folds formed over early faulted monoclinal structures or other perturbations in the multilayer geometry.

The lack of minor F_g folds suitable for constructing dip isogons or measuring bed thicknesses around the fold hinges means that the fold class could not be determined. However, measurements made around Halifax in the Halifax Formation (Keppie, 1976) revealed that the sandstone layers generally have constant bed thickness around fold hinges (i.e. Class 1B; Ramsay, 1967) whereas slate layers have thickened fold hinges (Class 1C-3; Ramsay, 1967). These observations indicate that flexural-slip, flexural-flow and tangential longitudinal strain mechanisms of folding were predominant, with, in addition, superimposed pure strain occurring mainly in the slates. The constant bed thickness of sandstone beds around fold hinges (Keppie, 1976) suggests that there is little internal strain perpendicular to the bedding in the sandstones. Deformed L_s lineations in stratiform quartz veins at the North Anticline were observed to be deformed by minor F_g folds (Fig. 7b). An example of measurements of these deformed L_s lineations shows a complex lineation locus (Fig. 12a) different from the small circle distribution normally produced by flexural-slip folding where the slip direction is perpendicular to the fold hinge. The observed deformed lineation locus is comparable to that produced by oblique flexural folding where the X-axis of bulk strain lies

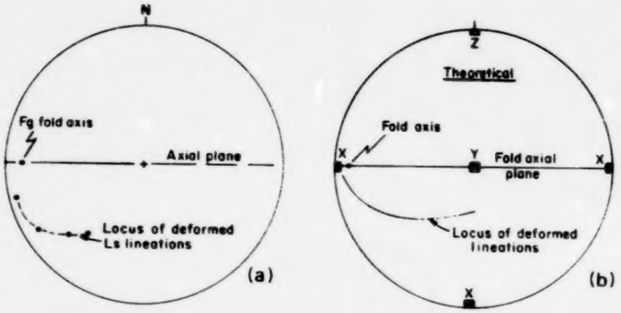
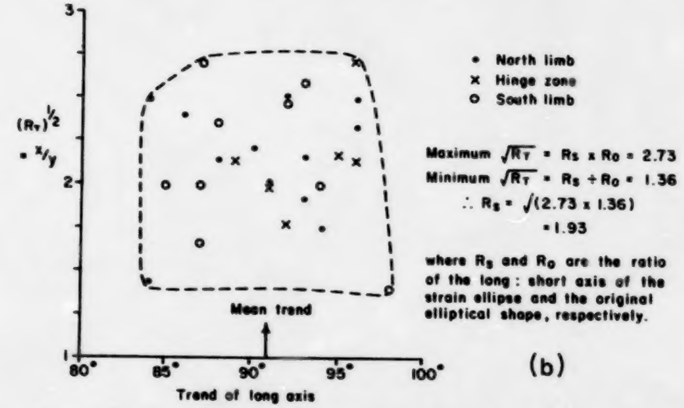


Figure 12a. Stereoplot of locus of L_s lineations in an early stratiform quartz vein deformed by a minor F_g fold, North Anticline.

b. Stereoplot of theoretical pattern of deformed lineations folded by an oblique flexural-folding mechanism with obliquely inclined bulk strain axes X, Y and Z.

close to the fold axis (Fig. 12b) (Ramsay, 1967; Keppie, 1974). This implies that the slip direction although variable in orientation lies close to the fold axis rather than perpendicular as is in the case of normal flexural-slip folding. In this connection, it is interesting to note that the long axes of sand volcanoes measured around the northern part of the North Anticline lie only 8° away from the fold axis (Fig. 9b). This is generally the case throughout the area. Rough measurements of the long and short axes of the sand volcanoes indicate a ratio of 1.9:1 for the long:short axis of the strain ellipse independent of the dip (Fig. 13). The similar strain ratio at various dips is explicable in terms of (i) an initial pure strain or flattening inferred from the prefold S_g cleavage development, (ii) followed by oblique flexural folding in which the sand volcanoes would suffer further strain only in the fold limbs, and followed by, (iii) late D_g flattening which would strain the sand volcanoes in the hinge more than in the limbs. Some indication of the orientation and relative magnitude of the bulk strain axes of the strain ellipsoid is given by the structures observed in deformed quartz veins and sandstone dykes of various orientations. In some places, such as around the North Anticline and at the Isaacs Harbour Lighthouse, pre-F_g stratabound quartz veins and sandstone dykes occur in a diverse orientation relative to bedding and cleavage (Fig. 7a, 13c). When viewed on surfaces approximately perpendicular to strike, these veins and dykes are generally folded except for those oriented close to the slaty cleavage (±ca. 10°) which are planar or with minor pinch and swell. On the other hand, on subhorizontal surfaces the veins display pinch and swell, boudinage and tension gashes of fibrous quartz in carbonate veins (Fig. 13c,d). The orientation of the quartz fibres and the tension gashes indicate that the X bulk strain axis is extensional, east-west and subhorizontal and slightly oblique to the fold axis and the slaty cleavage (Fig. 13c). On surface, approximately perpendicular to X, the lack of both folds and extensional structures in veins approximately parallel to the slaty cleavage indicates that the Y

Figure 13a. Photograph of deformed sand volcanoes on the top of a sandstone bed with long axes approximately parallel to the bedding/cleavage intersecton lineations, L_g.



Maximum $\sqrt{R_T} = R_s \times R_o = 2.73$

Minimum $\sqrt{R_T} = R_s \div R_o = 1.36$

$\therefore R_s = \sqrt{(2.73 \times 1.36)}$

$= 1.93$

where R_s and R_o are the ratio of the long : short axis of the strain ellipse and the original elliptical shape, respectively.

Figure 13b. Graph of the long/short axes (X/Y) of sand volcanoes plotted against the orientation of the long axis, northern part of North Anticline, Isaacs Harbour.

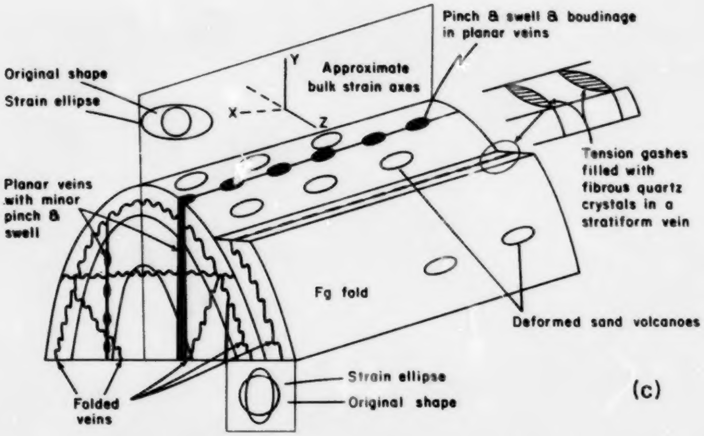

Pinch & swell & boudinage in planar veins
Original shape
Strain ellipse
Y
Approximate bulk strain axes
X
Z
Tension gashes filled with fibrous quartz crystals in a stratiform vein
Planar veins with minor pinch & swell
Fg fold
Deformed sand volcanoes
Strain ellipse
Original shape
(c)
Folded veins

Figure 13c. Schematic diagram of the structures observed in sandstone dykes and stratiform and stratabound veins and inferred approximate orientations of bulk strain axes, X, Y, and Z.

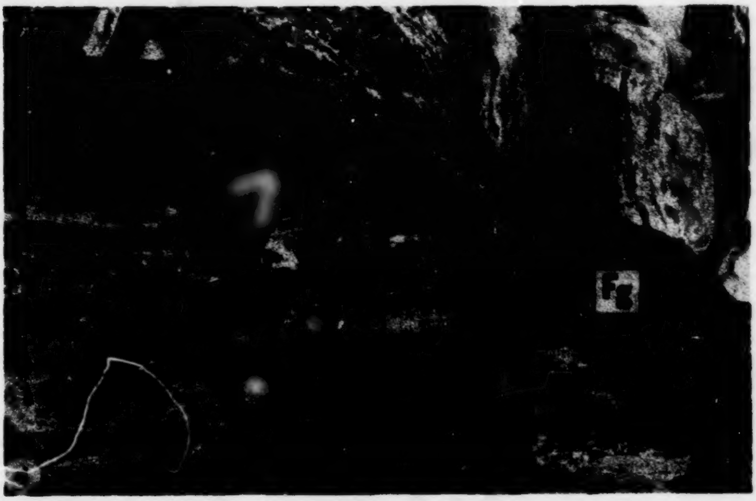


Figure 13d. Photograph of tension gashes filled with fibrous quartz crystals in a stratiform carbonate vein deformed by F_g folds, ca. 50 m northeast of Isaacs Harbour Lighthouse.

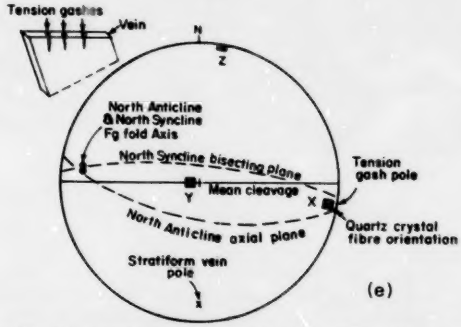

Tension gashes
Vein
N
Z
North Anticline
& North Syncline
Fg fold Axis
North Syncline bisecting plane
Tension gash pole
Mean cleavage
Y
X
North Anticline axial plane
Quartz crystal fibre orientation
Stratiform vein pole
(e)

Figure 13e. Stereoplot of tension gashes filled with fibrous quartz from North Anticline, Isaacs Harbour, showing inferred bulk strain axes relative to F_g folds.

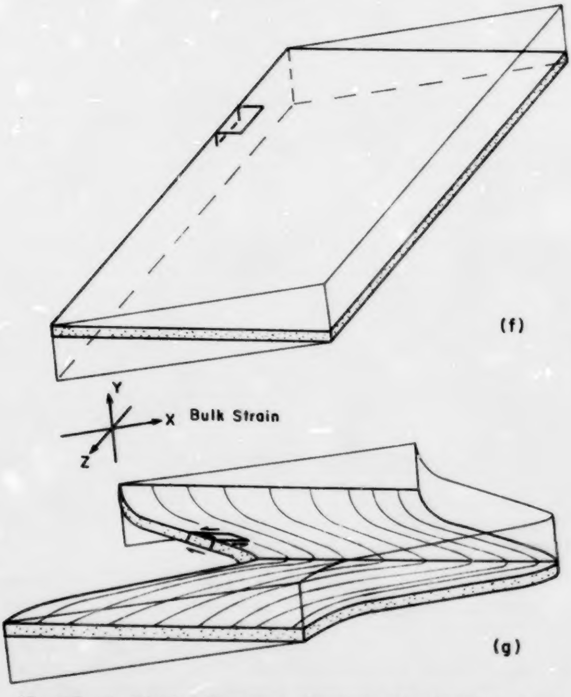

(f)
Y
X
Z
Bulk Strain
(g)

Figure 13. (f and g) Block diagrams showing (f) initial horizontal bed deformed by (g) oblique flexural folding with obliquely oriented bulk strain axes X, Y and Z.

intermediate bulk strain lies in or close to the slaty cleavage and involved minor or no finite strain (Fig. 13f, g). The Z bulk strain axis is approximately north-south and subhorizontal. Comprehensive measurements of these structures must await next field season.

The D_g phase of deformation also produced pressure solution cleavage in the sandstone layers defined by seams rich in phyllosilicates: chlorite, muscovite and biotite (Figs. 2a, 4) (O'Brien, this volume). In general the pressure solution cleavage is not parallel to the F_g fold axial planes, and the bedding/pressure solution cleavage intersection lineations are not parallel to the F_g fold axes (Figs. 8a,b, 14). A multistage development of the pressure solution cleavage may be observed in the limbs of the F_g folds (Fig. 15). Here several generations of anastomosing and irregular pressure solution cleavages may be observed intersecting one another. Preliminary observations suggest that the earliest pressure solution cleavage has the shallowest dip and later cleavages are progressively steeper. Even in the F_g fold hinges several generations of intersecting pressure solution cleavages may be observed (e.g. South Anticline). In the special case where the pressure solution cleavage/bedding intersection lineations are parallel to the F_g fold axis (e.g. New Harbour Syncline at New Harbour), the single pressure solution cleavage becomes very strongly developed and is planar and regularly spaced. These observations suggest that the pressure solution cleavage began to form early during the D_g phase of the deformation and continued throughout the fold development. The general obliquity of the pressure solution cleavage/bedding intersection lineations to the F_g fold axes is also explicable in terms of dextral shear on the early faulted monoclinal fold limbs in addition to the nonparallel geometric relations observed in conical folds (Fig. 9).

In the pelitic rocks, the D_g phase of deformation produced a slaty cleavage defined by aligned chlorite, muscovite and biotite. ^{40}Ar/^{39}Ar total gas ages on Halifax slates from the Lunenburg and Annapolis Valley area give 400 to 415 Ma (Reynolds and Muecke, 1978) and are interpreted as giving the age of the slaty cleavage, i.e. Early Devonian Acadian Orogeny (Keppie et al., in press). In general, the slaty cleavage is not parallel either to the F_g fold axial planes or the pressure solution cleavage, and bedding/slaty cleavage intersection lineations are not parallel to either the F_g fold axis or the bedding/pressure solution cleavage intersection lineations (e.g. Fig. 16). However, the slaty cleavage is usually steeply dipping and appears to mainly record the late flattening increments of strain (O'Brien, this volume). In places, a penetrative foliation may also be observed which cuts across the pressure solution seams. This foliation may also be due to these late flattening increments of strain.

In summary, it appears that some of the D_g structures were produced in response to dextral shear movements on early faulted monoclinal fold limbs. Folds were preferentially developed along these pre-existing structures in an en echelon arrangement, and during progressive strain increments were rotated towards the plane of shear (Fig. 11a). Pressure solution and slaty cleavages also formed at various stages during this deformation. Their formation recorded a particular stage in the bulk strain history after which they were also rotated towards the shear plane.

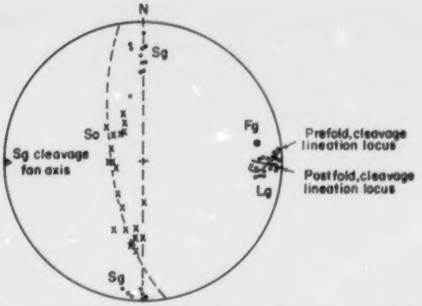


Figure 14. Stereoplot of structural data from South Anticline, Ragged Point, Isaacs Harbour, showing generally cylindrical F_g fold in bedding plane poles S_o, with an axial plane which is not coplanar with the pressure solution cleavage, S_g. Comparison of the bedding/cleavage intersection lineation pattern (L_g) with theoretical locii where the cleavage is either pre- or postfolding, while not unequivocal, suggests that the pressure solution cleavage is most likely to be prefolding.

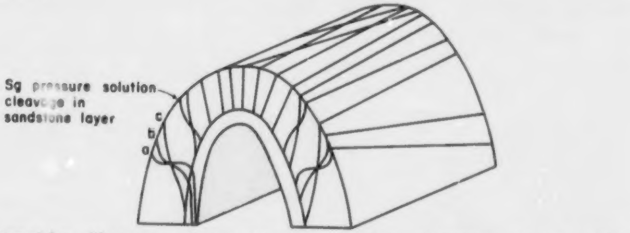


Figure 15. Schematic diagram of pressure solution cleavage in F_g fold showing sequential development of pressure solution seams a, b, and c.

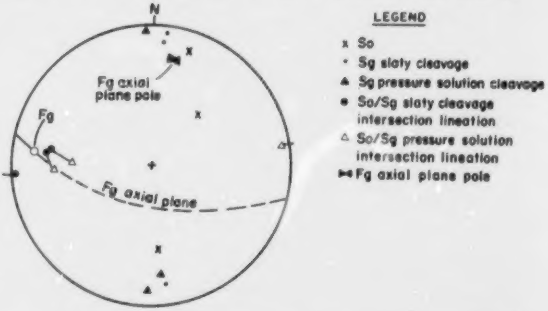


Figure 16. Stereoplot to show nonparallelism of S_g pressure solution cleavage, slaty cleavage and F_g fold axial planes and their respective intersections, L_g, with bedding in the North Anticline, Isaacs Harbour. Tie lines join intersection lineations measured at the same place.

Since the various D_g structures formed at different stages in the strain history they are not parallel. The deformed L_s lineations, deformed sand volcanoes, the orientation of D_g crystal fibres and the spatial distribution of boudinage suggest that the long X-axis of the bulk strain ellipsoid lies at a small angle to the F_g fold axes. The Z bulk strain axis is generally north-south and subhorizontal and the Y intermediate bulk strain axis is approximately vertical and involves little or no finite strain. This arrangement of the bulk strain axes explains why the F_g fold axes and associated lineations and deformed primary sedimentary lineations are consistently subhorizontal throughout the Meguma Terrane. Thus, all linear structures would tend to be rotated towards the subhorizontal finite extensional direction. These conclusions are consistent with the ca. 370-475 km dextral movement inferred to have taken place on the Minas Geofracture during the Acadian Orogeny (Keppie, 1982a).

D_c Structures (Acadian)

The D_g phase of deformation was followed by the D_c phase named after Country Harbour where the D_c structures are well developed (O'Brien, this volume). The D_c phase of deformation is characterized by a sporadic, but regionally pervasive subhorizontal crenulation cleavage S_c defined by chlorite, muscovite and biotite and crenulations of S_g and S_o. They are preferentially developed in the pelitic layers and rarely deform the sandstone beds (Fig. 17). No major D_c structures have yet been discovered. Regionally, the S_c poles define a partial great circle distribution about an east-west to east-northeast—west-southwest axis (Fig. 8d), which is parallel or slightly oblique to the F_c and F_g fold axes (Fig. 8c). While some of this variation may be explained by cleavage fans, there also appears to be a systematic relationship between the orientation of the S_c cleavage and the orientation of the bedding. Thus across the North Anticline and the North Syncline at Isaacs Harbour, S_c dips in the same direction as the bedding but at a shallower angle (Fig. 17c). The same relationship occurs across the Upper Seal Harbour Anticline on Country Harbour, however, here the S_c cleavage dips more steeply (Fig. 17d) and the range in attitude of S_c is greater than at Isaacs Harbour. Thin section examination of the S_c crenulation cleavage from the Upper Seal Harbour Anticline and Isaacs Harbour reveals that both the S_c crenulation cleavage and syn- to post-S_c biotite porphyroblasts are deformed by folds with axial planes approximately parallel to the S_g foliation. Thus, while it is possible that some of the variation in S_c attitude may be due to cleavage fanning it is also due to post-D_c (?Hercynian) tightening of the F_g folds. This would cause a wider dispersion of the great circle distribution of S_c poles. This post-D_c deformation is probably related to the (?)Hercynian deformation which becomes intense north from the Stormont Syncline.

It is postulated that the D_c phase of deformation was due to gravitational collapse as a consequence of the relaxation of the D_g stresses. Thus, the strain axes retained their orientations from D_g to D_c and merely changed their relative magnitude. The vertical axis became the Z-axis, the north-south subhorizontal axis became the X-axis and the east-west subhorizontal axis became the Y-axis.

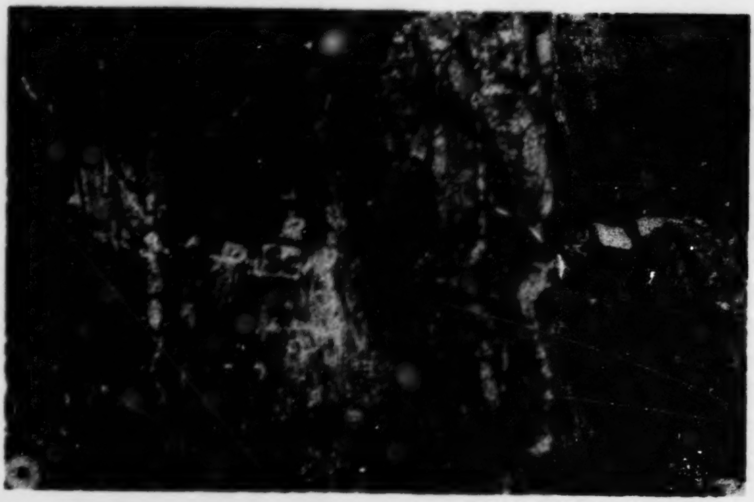


Figure 17a. Photograph of subhorizontal S_c crenulations cleavage fan approximately parallel to the axial plane of a minor F_c fold, ca. 120 m north of the North Anticline, Isaacs Harbour.

Figure 17b. Photograph of subhorizontal S_c crenulation cleavage cutting pelitic rocks and deforming slaty cleavage, S_g, Isaacs Harbour Lighthouse.

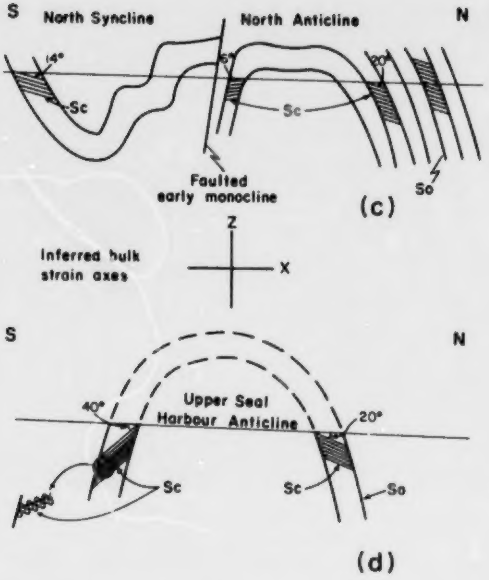


Figure 17c. Diagrammatic cross-section of the S_c crenulation cleavage attitudes around the North Anticline and North Syncline, Isaacs Harbour.

17d. Diagrammatic cross-section of the S_c crenulation cleavage over the Upper Seal Harbour Anticline on the eastern side of Country Harbour.

Regional Static Metamorphism

The regional metamorphic grade appears to have risen from the greenschist facies during the D_s, D_g and D_c phases of deformation into the amphibolite facies immediately following the D_c phase of deformation. This metamorphism rises from the greenschist facies in the south to the amphibolite facies in the north. This regional static metamorphic event produced large porphyroblasts of biotite, garnet, staurolite, andalusite and cordierite which generally grow over the earlier foliations. This rise in metamorphism appears to have started during the latter part of D_c in the Country Harbour area because large biotite porphyroblasts both grow over the F_c crenulations and are themselves deformed by D_c deformation (Muecke, personal communication, 1982). Elsewhere in the Isaacs Harbour area similar biotite porphyroblasts are post-D_c. The minerals produced during this static regional metamorphism indicate that it is low pressure and similar to the Pyrenean metamorphism found in the southwestern part of the Meguma Terrane (Keppie and Muecke, 1979).

West of Country Harbour, the Sherbrooke pluton although roughly coincident with a local metamorphic high, in detail cuts across the garnet and staurolite isograds (Smith, 1981). This pluton has yielded a whole rock Rb/Sr isochron of 369 ± 2 Ma (Keppie et al., work in progress) thereby providing a latest Upper Devonian upper limit on all of the preceding events.

(?)Hercynian Structures

Along the Stormont Syncline in the northern part of the Isaacs Harbour area, a later east-west, steeply dipping foliation defined by mica deforms all the earlier structure and wraps around the static porphyroblasts (Fig. 18a). Preliminary reconnaissance farther north reveals that this later foliation becomes more pervasive in belts interpreted as shear zones separated by areas where the earlier structures are preserved. Preliminary examination of the Sangster Lake pluton revealed that it is deformed by two planar fabrics. The east-northeast to west-southwest foliation is defined by flattened crystals of quartz, feldspar and mica. The east-west planar fabric is discrete planes along which the granitoid crystal phases have been mylonitized and offset dextrally, accompanied by recrystallization of fine grained sericite and quartz producing a subhorizontal mineral lineation (Fig. 18b). It is postulated that these fabrics were produced at the same time as the flattening foliation representing the XY plane of the strain ellipsoid, associated with a dextral shear fabric.

South of the Stormont Syncline the effects of this deformation die out. It is possible that this deformation caused some tightening of the Upper Seal Harbour Anticline as suggested earlier. Also along the New Harbour Sycline at Isaacs Harbour, an isolated fold with an axial plane much steeper than those of F_c deforms the S_g slaty cleavage (Fig. 18c). In this connection it is interesting to note the presence of some north-south vertical veins (Fig. 18d) which appear to cut across the F_g folds and yet are themselves gently folded and cut by the S_g foliation (Haynes, this volume; O'Brien, this volume). It is postulated that the gentle deformation of these veins may be due to later (?)Hercynian deformation which reactivated the steep S_g cleavage. Further work on these structures is required.

On the western side of Country Harbour, these (?)Hercynian fabrics become pervasive in the Meguma Group at the Waternish Syncline and the Bull Ridge pluton is also deformed throughout in the same way as the Sangster Lake pluton. Farther south they also appear to die out. Thus, it appears that this (?)Hercynian deformation increases in intensity towards the Minas Geofracture which forms the northern boundary of the Meguma Terrane. It is inferred that these fabrics were produced by dextral movements on the east-west Minas Geofracture of at least 165 km during Permo-Carboniferous times (Keppie, 1982a). The en echelon east-northeast—west-southwest folds in the Early Carboniferous rocks in the St. Marys graben immediately north of the Meguma Terrane (Keppie et al., 1982) may also be attributed to these dextral movements. The curved shape of the Meguma Terrane and the major folds in the Meguma Terrane are also probably partly the result of these movements.

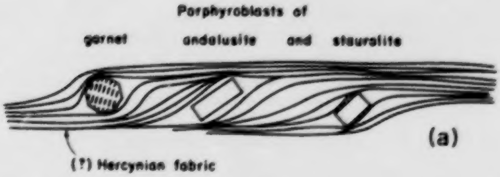

Porphyroblasts of
garnet
andalusite
and
staurolite
(a)
(?) Hercynian fabric

Figure 18a. Sketch of (?)Hercynian foliation wrapping around static garnet, staurolite and andalusite crystals, some of which contain the older S_g foliation as inclusion trails.

Figure 18b. Photograph of (?)Hercynian flattening and shear planar fabrics deforming the Bull Ridge pluton at the Radio Tower.

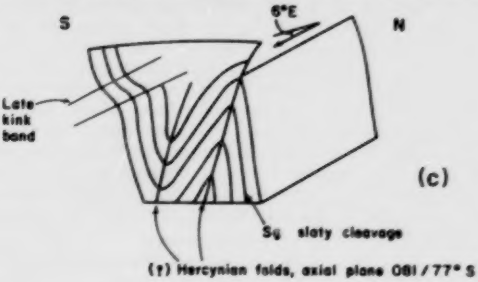

S
6°E
N
Late kink band
(c)
Sg slaty cleavage
(?) Hercynian folds, axial plane 081/77° S

Figure 18c. Sketch of (?)Hercynian fold of the S_g slaty cleavage in the Halifax Formation, New Harbour Syncline, western side of Isaacs Harbour.

Figure 18d. North-south vertical quartz vein cut by S_g pressure solution cleavage inferred to be reactivated during (?)Hercynian deformation (photo by S. J. Haynes).

Kink Bands, Faults, Riedel Shears and Cross Veins

The last events recorded in the Isaacs Harbour area produced several sets of kink bands and Riedel shears, the northwest-southeast sinistral faults and late crosscutting quartz veins. The northwest-southeast, steeply dipping, sinistral kink bands are the most common (Fig. 8e,f, 19a). They are spatially associated with northwest-southeast Country Harbour, Isaacs Harbour and New Harbour Faults which offset the F_g fold traces in a sinistral sense (Fig. 1). This suggests that they are genetically related. The rare northeast-southwest steeply dipping, dextral kink bands probably form the conjugate pair with the northwest-southeast kink bands. Associated with some of these kink bands is a set of en echelon joints oriented obliquely to the kink band. These joints are usually deformed by the middle limb of the kink band (Fig. 19b). These en echelon joints are interpreted as Riedel shears which formed in response to the same stresses that later during the progressive strain produced the kink bands and northwest-southeast faults.

There are also a few gently dipping kink bands (Fig. 8f). The northeasterly to easterly dipping kink bands are sinistral, whereas these dipping southeasterly are dextral. This suggests that they may be a conjugate set with an approximately vertical maximum stress axis (Fig. 19c).

There is also the sporadic development of north-south, vertical shear zones with associated en echelon, Riedel shears (Fig. 19d). The

Figure 19a. Photograph of northwest-southeast steeply dipping, sinistral kink bands of S_g cleavage adjacent to Isaacs Harbour Fault, Isaacs Harbour Lighthouse.

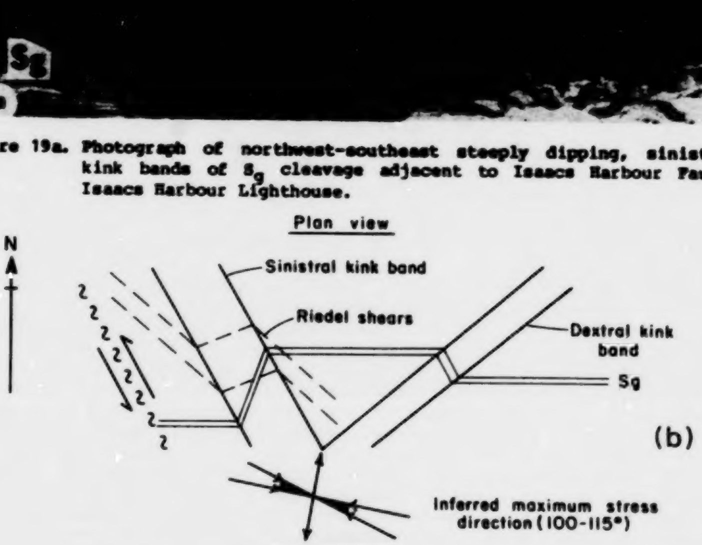

Plan view
N
Sinistral kink band
Riedel shears
Dextral kink band
Sg
(b)
Inferred maximum stress direction (100-115°)

Figure 19b. Schematic plan view of conjugate northwest-southeast sinistral kink bands and northeast-southwest dextral kink bands, Riedel shears, northwest-southeast sinistral faults and inferred stress directions.

orientation of the Riedel shears relative to the shear zones is both clockwise and anticlockwise. This indicates that the movements were dextral and sinistral respectively, on these shear zones with the maximum stress oriented northeast-southwest and northwest-southeast respectively (Fig. 19e).

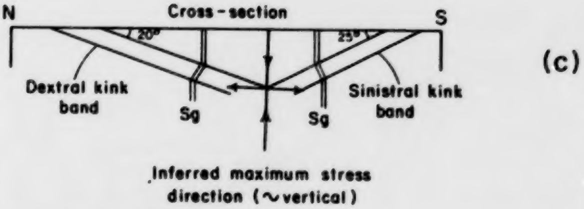

N
Cross - section
S
20°
25°
Dextral kink band
Sg
Sg
Sinistral kink band
Inferred maximum stress direction (~vertical)
(c)

Figure 19c. Schematic cross-section of gently dipping (?) conjugate kink bands and inferred stress directions.

Figure 19d. Photograph of vertical, north-south, sinistral shear zone with obliquely oriented Riedel shears within the shear zone, North Anticline, Isaacs Harbour.

The north-south shear zones are sometimes filled with quartz-K-feldspar-sericite-carbonate veins which are especially common at Ragged Point (Fig. 1). Less commonly the northwest-southeast kink bands-shear zones are also filled by these veins. Some east-west late veins are also present in the area.

At this stage, the relative ages of these kink bands and shears is unclear. However, the northwest-southeast kink bands and faults post-date the (?)Hercynian structures because they deformed them adjacent to the Country Harbour and New Harbour Faults. Movement on the northwest-southeast faults may be related to the opening of the Bay of Fundy during the

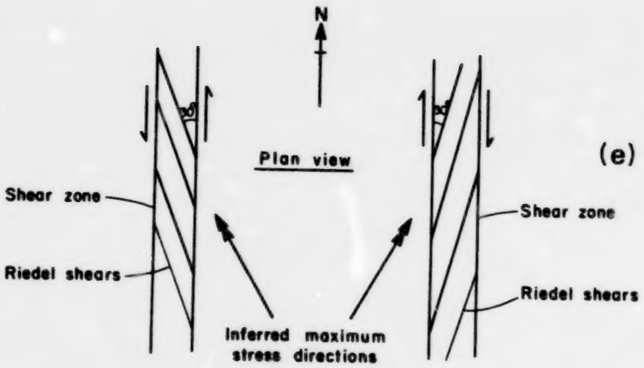


Figure 19e. Diagrammatic plan view of vertical north-south shear zones and associated Riedel shears with inferred stress directions.

Triassic and Jurassic. At this time, there was about 75 km sinistral movement on the east-west Minas Geofracture (Keppie, 1982a) some of which may have been related to the development of the St. Marys graben and related sinistral northwest-southeast faulting.

DISCUSSION

In the light of the emerging data on the Meguma Terrane, it is appropriate to examine the implications for gold exploration. If the hypothesis that the early auriferous veins were produced by hot springs above fissure conduits (Haynes, this volume) proves to be correct, then how may they be located? The inferred association of the fissures with syndepositional faulted monoclinal folds suggests a structural guide and to this end the location of the steep limbs of monoclinal folds in the eastern Meguma Terrane is shown in Figure 20. A geochemical halo might be predicted around such hot spring veins. Also these localities may have geophysical signatures for instance: magnetic anomalies if the iron occurs in magnetic minerals and EM anomalies if the carbon forms graphite.

Later deformation appears to have mobilized quartz and gold in the auriferous veins and the D_g phase is the most important in this respect. Minor mobilization of quartz and gold in F_g fold hinges of stratiform veins during D_g explains the empirical association of gold districts with dilational features such as F_g fold domes with the high curvature indices and conical folds (Keppie, 1976) which, as noted earlier, often appear to nucleate at the steep limbs of the early monoclinal folds.

In the southwestern part of the Meguma Terrane there is a general absence of gold deposits and occurrences above the andalusite-staurolite-cordierite isograd of metamorphism. This suggests that the high grade metamorphism also remobilized the gold driving it out to lower grades. In this respect, the presence of gold deposits such as Cochrane Hill and Forest Hills in the high grades of metamorphism in the eastern Meguma Terrane requires an alternative explanation. The host rocks at Cochrane Hill

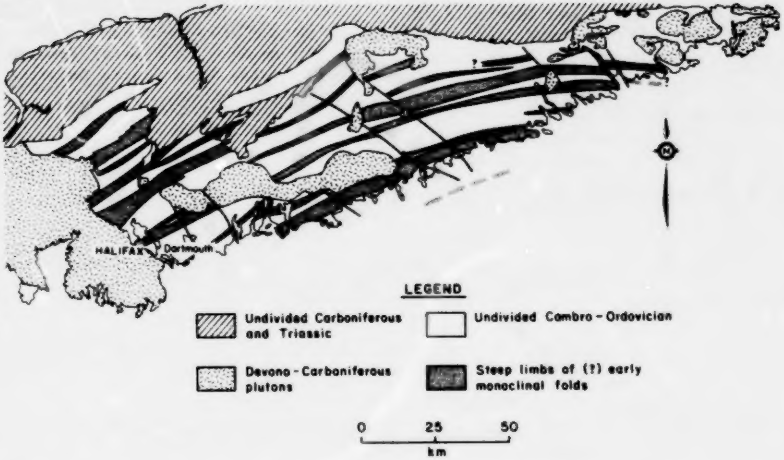

HALIFAX
Dartmouth
?
LEGEND
Undivided Carboniferous and Triassic
Undivided Cambro-Ordovician
Devono-Carboniferous plutons
Steep limbs of (?) early monoclinal folds
0
25
50
km

Figure 20. Map of the steep limbs of (?)early monoclinal folds in the eastern Meguma Terrane.

and Forest Hills display the effects of post-amphibolite facies deformation of probable Hercynian age. Thus one possible explanation for the presence of gold here may be that the gold was remobilized along Hercynian shear zones (Smith, this volume), the location of which could prove a useful exploration guide. Alternatively, the gold may not have been driven out by the high grade metamorphism due to different chemical conditions.

ACKNOWLEDGMENTS

I thank my colleagues on the Meguma Gold Project for much useful discussion. This project was funded by the Nova Scotia Department of Development under the Canada-Nova Scotia Co-operative Mineral Program 1981-84.

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THE STRUCTURE OF THE MEGUMA GROUP BETWEEN GEGOGAN HARBOUR AND COUNTRY HARBOUR, GUYSBOROUGH COUNTY*

B. H. O'Brien

ABSTRACT

A multiphase history of Acadian deformation is proposed for Meguma Group rocks between Gegogan Harbour and Country Harbour, Guysborough County. Three episodes of coaxially superimposed deformation are recognized on the basis of regionally developed, minor structures. In ascending order they are here defined as the Sherbrooke deformation (D_s), the Guysborough deformation (D_g) and the Country Harbour deformation (D_c). Cleavages, folds, lineations and vein-filled fractures were produced during successive increments of a progressive deformation. These minor structures are developed on only one group of major, east-west trending folds. They record the various effects of the D_s, D_g and D_c deformations in producing the present shape and orientation of the regional folds. The latest movements on the major faults postdate the formation of the major folds and the intrusion of the 369 ± 2 Ma Sherbrooke pluton.

INTRODUCTION

This report deals with the analysis of minor and major structures found in a small, relatively well exposed sector of the Meguma Group. Part of the area between Gegogan Harbour and Country Harbour was previously mapped by Smith (1980) and the reader is referred to his work for information on the general geology. The data presented are largely gleaned from detailed measurements and unpublished maps and cross-sections prepared by the writer. The structural discussions herein centre on the metasedimentary rocks at the expense of the auriferous quartz veins in the Meguma Group. The tectonic features of the vein arrays in relation to host rock deformation have been treated briefly elsewhere (O'Brien, 1982).

The regional structure of the area between Gegogan Harbour and Country Harbour is quite simple. Here, E. R. Faribault (1893) determined the structure of the Meguma Group on the scale of one inch to one mile by tracing the lithostratigraphical contact between the Halifax and the Goldenville Formations. His maps and cross-sections show the distribution of these Formations to be controlled by large scale folds and faults (Fig. 1). Field mapping during 1982 has verified that these upward-facing folds are commonly tight to isoclinal, that their hinge lines are doubly, but generally shallowly plunging and that their axial surfaces are steep. Regionally developed slaty cleavage is attendant to such folds. Faults and joints are oriented both parallel and oblique to the slaty cleavage. These features, together with the linear outcrop of the shale-dominated units (Fig. 1), point generally to a slate belt association (Hobbs et. al, 1976).

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*Contribution to Canada-Nova Scotia Co-operative Mineral Program 1981-84. Project carried by Nova Scotia Department of Mines and Energy and by Geological Survey of Canada.

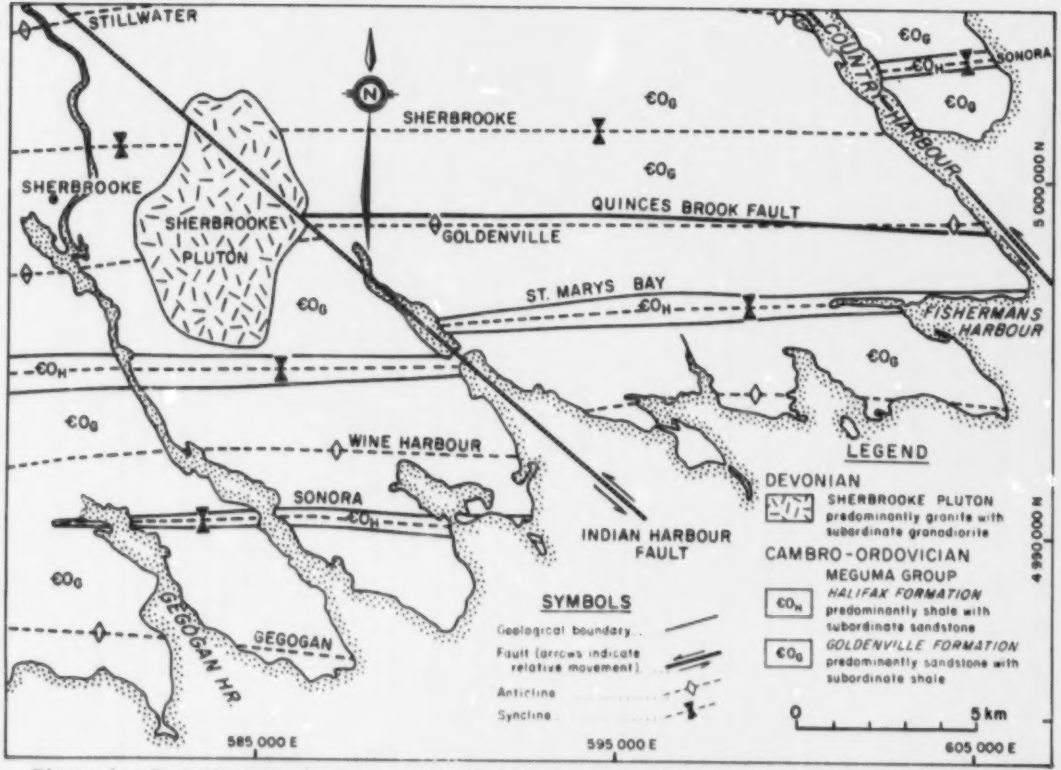

STILLWATER
SHERBROOKE
SHERBROOKE
SHERBROOKE PLUTON
N
€O_G
QUINCES BROOK FAULT
GOLDENVILLE
ST. MARYS BAY
€O_H
COUNTRY HARBOUR
SONORA
FISHERMANS HARBOUR
WINE HARBOUR
SONORA
INDIAN HARBOUR FAULT
GEGOGAN
GEGOGAN HR.
5 000 000 N
4 990 000 N
585 000 E
595 000 E
605 000 E
0
5 km
LEGEND
DEVONIAN
SHERBROOKE PLUTON predominantly granite with subordinate granodiorite
CAMBRO-ORDOVICIAN
MEGUMA GROUP
€O_H HALIFAX FORMATION predominantly shale with subordinate sandstone
€O_G GOLDENVILLE FORMATION predominantly sandstone with subordinate shale
SYMBOLS
Geological boundary
Fault (arrows indicate relative movement)
Anticline
Syncline

Figure 1. General geological map of the Gegogan Harbour-Country Harbour area, Guysborough County. For location see Keppie et al., this volume (Meguma Gold Project, Fig. 1).

In contrast, local structures are very complex. Data will be presented to show that the superimposed minor structures record sequential episodes in a progressive but discontinuous deformation. Inhomogeneous shortening in space and in time has meant that different parts of the major structures illustrate different increments of the total deformation.

MINOR STRUCTURES

In the area surveyed map scale interference patterns are conspicuously absent and, therefore, the minor structures yield the strongest evidence for multiphase deformation. Because they are regionally developed, the minor structures are used to establish the sequence of deformational episodes. The areas which best display these structures lend their names to the regional deformations (cf. Tobisch et al., 1970). In ascending order they are here defined as: the Sherbrooke deformation (D_s), the Guysborough deformation (D_g), and the Country Harbour deformation (D_c).

The Sherbrooke Deformation

Minor structures produced during the Sherbrooke deformation include cleavage, localized folds and, less commonly, vein-filled fractures. The Sherbrooke region comprises the largest area of least modified D_s structures.

CLEAVAGE

Variably penetrative S_s cleavage is commonly encountered and widely developed. In thin section it is seen to be a grain alignment cleavage (Fig. 2). In gently dipping rocks S_s cleavage has a shallow dip and forms a small angle with bedding. Of particular importance, however, is the fact that in many steeply dipping rocks undulatory S_s cleavage also dips gently, thereby making a large angle with the bedding (Fig. 3). In places steep beds displaying this type of cleavage-bedding relationship are hundreds of metres thick and it is, therefore, unlikely that such successions occur in the core of regional recumbent folds. Evidence supporting this view comes from two observations. Firstly, there are generally few, subvertical beds with steeply dipping, downward facing (cf. Shackleton, 1958) S_s cleavage. Common occurrences would be predicted however, if both S_0 (bedding) and S_s were steepened by fold limb rotation during post D_s deformation (Fig. 3). Secondly, most rocks in the Meguma Group in the area studied are observed to be right way up or to young in a consistent direction between the axial traces of the major folds and they are nowhere regionally inverted. A suggested explanation of the unique bedding-cleavage and younging relationships is that the S_s cleavage is imposed on large scale, gently plunging, asymmetrical, F_s step folds (Fig. 3).

FOLDS

Like most minor fold structures in the Meguma Group F_s folds are rare. To date, examples on the centimetre scale have been found only in the environs of laminated, stratiform quartz veins. There both vein and bordering host rock are isoclinally folded by F_s and cleaved axial planar by S_s (Fig. 4). Stratiform quartz veins generally mark the sites of

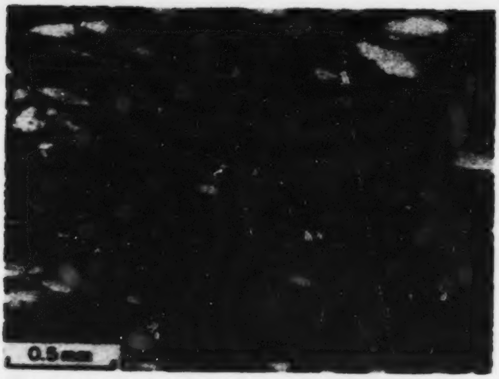


Figure 2. Photomicrograph of S_s cleavage outlined by a preferred alignment of detrital quartz and feldspar grains. In the matrix, metamorphic muscovite and biotite define S_s. Plane light.

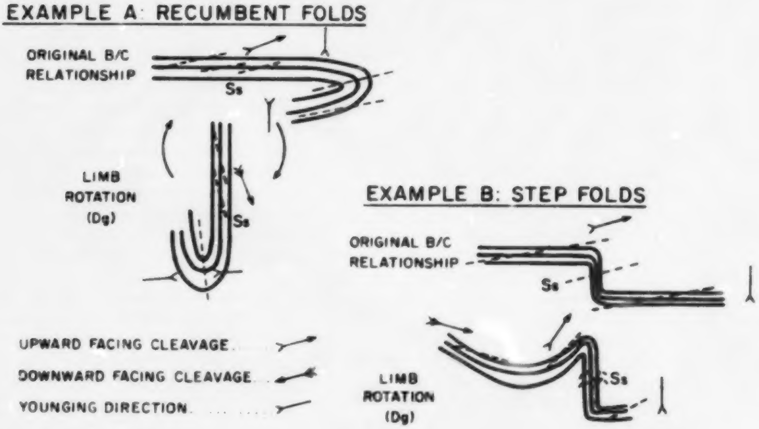

EXAMPLE A: RECUMBENT FOLDS
ORIGINAL B/C RELATIONSHIP
Ss
LIMB ROTATION (Dg)
Ss
EXAMPLE B: STEP FOLDS
ORIGINAL B/C RELATIONSHIP
Ss
UPWARD FACING CLEAVAGE
DOWNWARD FACING CLEAVAGE
YOUNGING DIRECTION
LIMB ROTATION (Dg)
Ss

Figure 3. Proposed S_o/S_s bedding-cleavage and structural facing relationships for e.g. A: F_s recumbent folds, and e.g. B: F_s step folds. Also indicated is the way in which these relationships are modified during D_g limb rotation.

relatively high intensity, D_s deformation and separate successions of beds illustrating relatively low intensity, D_s deformation (Fig. 5). Megascopic F_s step folds have been observed east of the area surveyed along the shoreline of Isaacs Harbour (see also Keppie, this volume). A sketch map of such a fold in plan view illustrates several important points (Fig. 6). Firstly, it is evident that vertical, east-west trending, slaty cleavage is imposed on both northeast-southwest and east-west striking rocks. The northeast-southwest striking, right-way-up beds dip as steeply as 60°NW, but shallow to as little as 15°NW over a distance measured in metres. This cannot be explained by abrupt F_g plunge culminations or depressions. The dip variation must, therefore, have been established prior to the formation of the slaty cleavage. Because the rocks young consistently in one direction, the outcrop pattern is most simply related to the presence of gently plunging, polyclinal, northeast-southwest trending, F_s step folds. The occurrence of gently dipping, northeast-southwest striking S_s cleavage supports this interpretation. Other important points arise from the observed rotation of 60° dipping beds and the resultant change in younging directions from northwest to north (Fig. 6). In the interval between F_s folding and the formation of S_g slaty cleavage the beds shown in Figure 6 were locally affected by a dextral shear couple. The sense of shear is such that the rotated beds young in the same direction as the east-west trending beds on the limbs of the major folds, i.e. the F_s megascopic folds and the F_g major folds have the same sense of vergence. Because the post-D_s rotation of F_s folds does not cause any repetition of the Meguma Group, the cryptic F_s structures are easily overlooked.

Some minor folds display both grain alignment cleavage (S_s) and slaty cleavage (S_g) and are spatially associated with small faults (Fig. 7). Unmodified S_s cleavage is commonly present on the gently dipping limb of these asymmetrical folds, while slaty cleavage prevails on the steep, slightly attenuated limb. This phenomenon appears to be regionally developed in the Sherbrooke area.

LINEATIONS

L_s lineations are generally rare. The original S_o/S_s intersection lineation is gently plunging where S_s has not been reorientated near bedding planes. Lineated, stratiform quartz veins display spectacular laminations and curvilinear striations (Fig. 8a, b). The quartz in these veins may have grown incrementally and syntectonically throughout a period of D_s extension (e.g. Morris and Barron, 1968; Durney and Ramsay, 1973). If this is so, then the fractures must have formed very early in the Sherbrooke deformation since the laminae are folded by F_s and cleaved by S_s (Fig. 4).

POST-D_s EFFECTS

In the above paragraphs the main features of the D_s minor structures are discussed without due mention of the effect of subsequent deformation on their general appearance. In some places, S_s cleavage can be traced continuously and uncharacteristically from the bottom to the top of more than one bed as an approximately planar surface. In all such occurrences S_s cleavage is observed to be upward facing on the bedding.

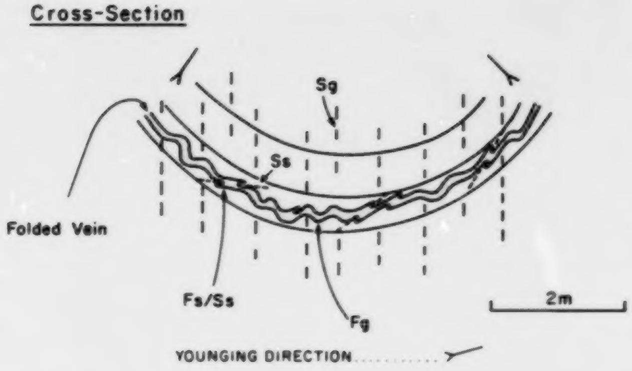

Cross-Section
Sg
Ss
Folded Vein
Fs/Ss
Fg
2m
YOUNGING DIRECTION

Figure 4. The relations of folded, stratiform, quartz veins to S_s and S_g cleavage and F_s and F_g folds. UTM 606600 4997400

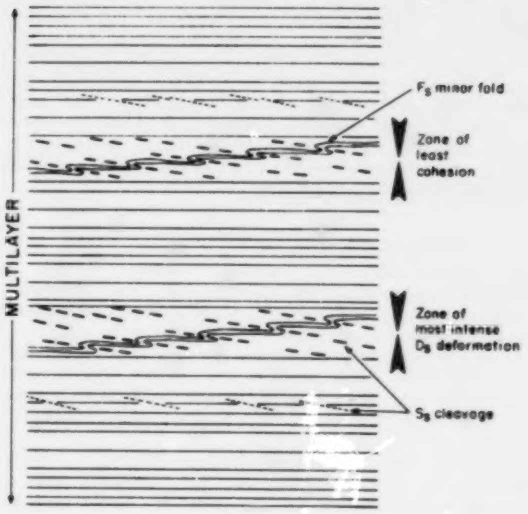

MULTILAYER
F_s minor fold
Zone of least cohesion
Zone of most intense D_s deformation
S_s cleavage

Figure 5. Hypothetical diagram depicting the sedimentary beds of the Meguma Group as a multilayer in which the sites of stratiform quartz veins coincide with zones of the most intense D_s deformation and the least D_s cohesion.

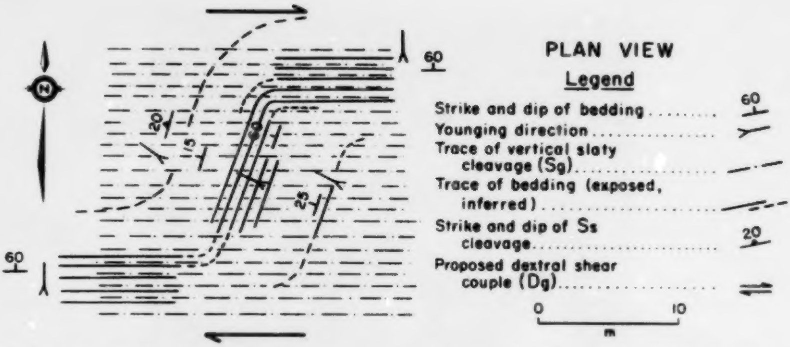

PLAN VIEW
Legend
Strike and dip of bedding 60
Younging direction ....
Trace of vertical slaty cleavage (Sg) ....
Trace of bedding (exposed, inferred) ....
Strike and dip of Ss cleavage 20
Proposed dextral shear couple (Dg) ....
0
10
m
N
60
60
20
15
60
25

Figure 6. Structural sketch map of a mesoscopic F_s step fold in plan view, F_g folds, S_g slaty cleavage and S_s grain alignment cleavage are also present. UTM 607500 5001000

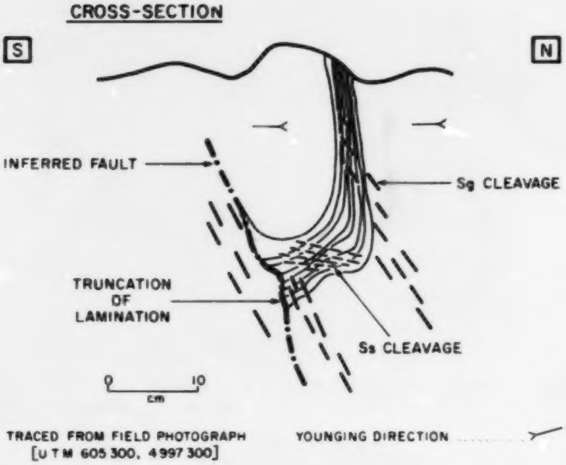

CROSS-SECTION
S
N
INFERRED FAULT
Sg CLEAVAGE
TRUNCATION OF LAMINATION
Ss CLEAVAGE
0
10
cm
TRACED FROM FIELD PHOTOGRAPH
[U T M 605 300, 4997 300]
YOUNGING DIRECTION ....

Figure 7. Field sketch of a gently plunging, asymmetrical, minor fold associated with a small fault. Note that S_s cleavage is dominant on the flat limb, and S_g cleavage is dominant on the steep limb.

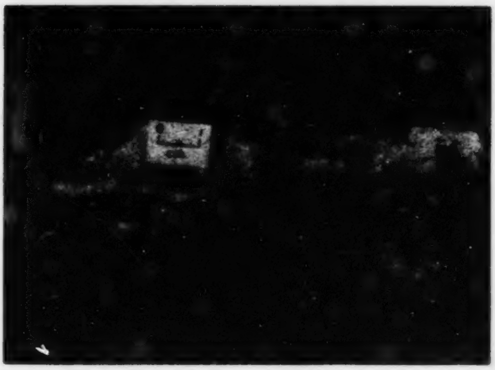


Figure 8a. Hand specimen of stratiform, gold-bearing vein displaying laminations of quartz separated by thin inclusion bands of darker coloured phyllosilicates.

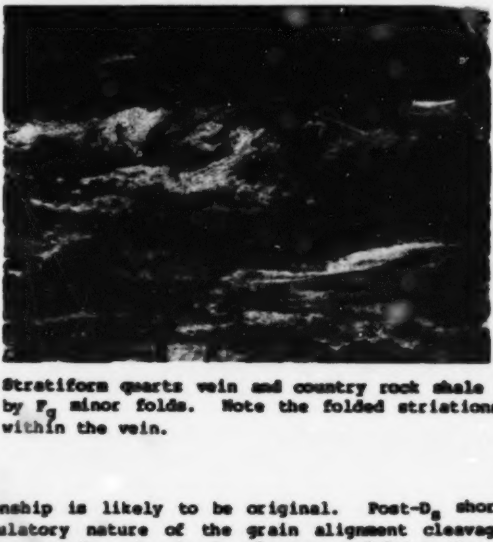


Figure 8b. Stratiform quartz vein and country rock shale deformed by F_g minor folds. Note the folded striations on and within the vein.

This relationship is likely to be original. Post-D_g shortening accounts for the undulatory nature of the grain alignment cleavage, particularly within the steep beds. As the S_g cleavage undulates through right-way-up beds it locally faces downward (Fig. 9). Where it is steepened to the near vertical in consistently right-way-up successions on fold limbs, S_g always faces upwards and there it can be difficult to discern geometrically from slaty cleavage. However, where post-D_g minor folds of bedding are tight to isoclinal, originally steep, slaty cleavage and steepened S_g cleavage locally illustrate different bedding-cleavage and facing relationships in the same bed (Fig. 10).

Figure 9. Downward-facing S_8 cleavage intersects right-way-up beds with a small angle and dips from the top left to the bottom right of the photograph. Upward facing S_g cleavage intersects bedding with a large angle and dips from the top right to the bottom left of the photograph.

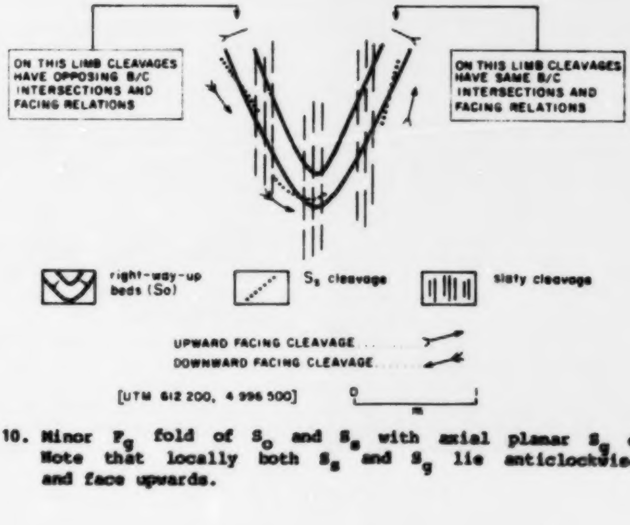

ON THIS LIMB CLEAVAGES HAVE OPPOSING B/C INTERSECTIONS AND FACING RELATIONS
ON THIS LIMB CLEAVAGES HAVE SAME B/C INTERSECTIONS AND FACING RELATIONS
right-way-up beds (So)
S_8 cleavage
slaty cleavage
UPWARD FACING CLEAVAGE
DOWNWARD FACING CLEAVAGE
[UTM 612 200, 4 996 500]
0
1
m

Figure 10. Minor F_g fold of S_0 and S_8 with axial planar S_g cleavage. Note that locally both S_8 and S_g lie anticlockwise of S_0 and face upwards.

The Guysborough Deformation

Minor structures characteristic of the slate belt association are ubiquitous in the area between Gegogan Harbour and Country Harbour. These D_g structures include cleavages, folds, lineations and vein-filled fractures. Reconnaissance studies indicate that they are also common throughout Guysborough County and that they are related to the major fold structures. The Guysborough deformation, as defined herein, is named in accordance with its regional importance.

CLEAVAGE

There are two, distinct, morphological varieties of Sg cleavage; one a pressure solution cleavage and the other a slaty cleavage. As opposed to preceding and succeeding foliations, S_g cleavage is everywhere upward facing. Strains produced during cleavage formation are generally low since several foliations are often observed in individual beds that contain delicate bedforms.

Spaced, S_g **pressure solution cleavage** is well developed in sandstone beds. Anastomosing seams or stripes several millimetres in width are rich in phyllosilicates and depleted in quartz (Fig. 11). They intersect bedding at various angles. Lithons of nonuniform width separate the stripes and are composed of sandstone grains which have suffered negligible pressure solution.

In vertical beds it is quite common to find pressure solution cleavage dipping as shallowly as 40° and undulatory grain alignment cleav-

Figure 11. Well developed S_g pressure solution cleavage in sandstones. The dark coloured seams or stripes are rich in phyllosilicates and depleted in quartz. The light-coloured lithons are zones in which the sandstone grains suffered negligible pressure solution. The seams intersect bedding at various angles.

age dipping as steeply as 30°. Here both foliations make a large angle with bedding and, for the most part, are inclined in the same overall direction. In such exposures, however, the variably facing S_s cleavage defines F_g minor folds to which the upward facing S_g cleavage is attendant (Fig. 12). Although pressure solution stripes can locally lie close to S_s, they are generally steeper than S_s and are distinguishable geometrically as well as morphologically. Field evidence of this type strongly suggests that pressure solution cleavage did not form during D_s and that it is characteristic only of the Guysborough deformation.

The orientation of pressure solution cleavage is characteristically variable, even in areas where there is a lack of post-S_g deformation. Pressure solution stripes vary in dip from 40° to 90° and in strike from 075° to 120° (Fig. 13). Compounded on this is the observation that within the same bed geometrically distinguishable, consistently upward facing, cleavage stripes display different amounts of dip. In many locations moderately dipping seams are folded and steepened abruptly so that they dip vertically near the bedding planes (Fig. 14). This is particularly noticeable near the margins of sandstone beds in steeply inclined rocks on the limbs of the major folds. In the central parts of some of these beds subvertical seams displace folded, moderately dipping seams (Fig. 14). Thus, active pressure solution cleavage is superimposed on passive, mechanically rotated, pressure solution cleavage. Lithons bounded by steeply dipping seams locally contain contorted, gently dipping seams (Fig. 15). In general, the active cleavage stripes are found to be steeper than the passive stripes. Where post-S_g cleavage is present in the same beds that display the active and the passive foliations, it provides an upper limit for D_g rotation and S_g superposition. It is evident that pressure solution cleavage did not form instantaneously, but that it evolved over a period of D_g time.

In places where sandstone beds outline parallel folds, pressure solution cleavage displays divergent fans in anticlines. The cleavage fan is most marked where the folds have a large apical angle. On the fold limbs the large angle of intersection between the stripes and the bedding (Henderson, this volume) probably means that moderately dipping, pressure solution cleavage formed early during buckling. This can be verified where there are steeper, active stripes in the same beds. The strongly fanned, probably early-formed, pressure solution cleavages have strikes (Fig. 13) that are highly oblique to bedding and to the axial trace of the major folds.

Slaty cleavage represents the second variety of S_g cleavage. It is well developed in shales, where it lies at various angles to bedding and forms convergent fans in synclines and divergent fans in anticlines. In most shale beds slaty cleavage is the pervasive foliation, although only locally does it transpose bedding. Less commonly, S_s cleavage is the most anisotropic surface in the shales [e.g. UTM 579900 4997550] and there S_g slaty cleavage is totally absent. In rare exposures, however, there is evidence of an incomplete transpositon of S_s by slaty cleavage (Fig. 16). In at least one locality [UTM 580450 4999400] S_g crenulation cleavage is seen in semipelites; S_s phyllosilicates define the associated F_g microfolds.

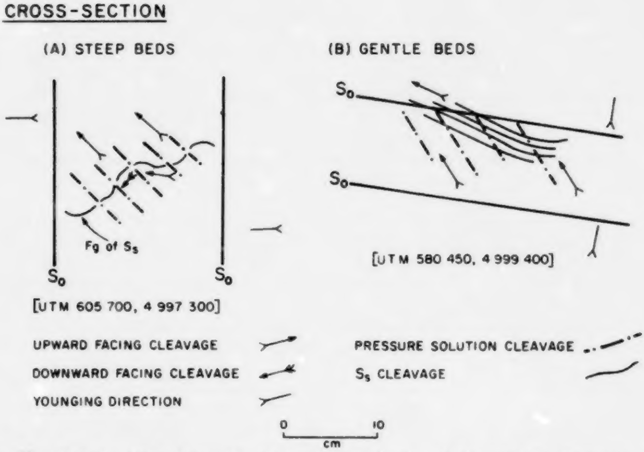

CROSS-SECTION
(A) STEEP BEDS
(B) GENTLE BEDS
Fg of S_s
S_0
S_0
S_0
S_0
[UTM 605 700, 4 997 300]
[UTM 580 450, 4 999 400]
UPWARD FACING CLEAVAGE
DOWNWARD FACING CLEAVAGE
YOUNGING DIRECTION
PRESSURE SOLUTION CLEAVAGE
S_s CLEAVAGE
0
10
cm

Figure 12. Local examples of the geometrical distinction between S_g pressure solution cleavage and S_s grain alignment cleavage in steeply and gently inclined beds.

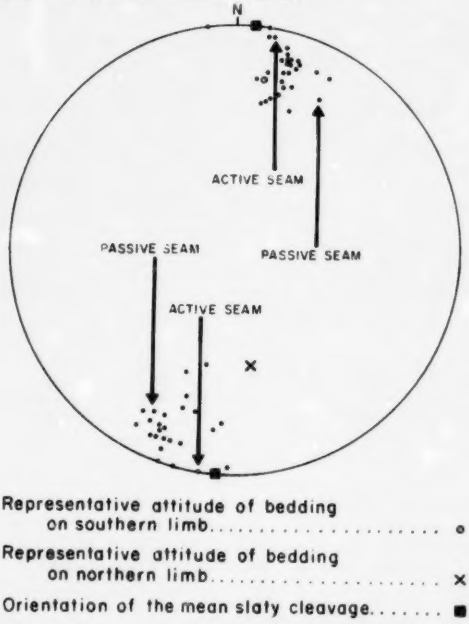


Figure 13. Stereoplot of poles to pressure solution cleavage from the core and both limbs of the Wine Harbour Anticline at Indian Harbour. Total of 55 measurements taken.

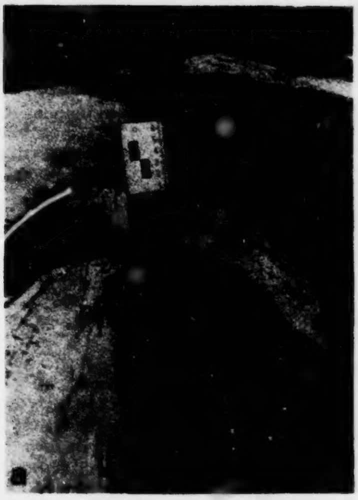


Figure 14a. Moderately dipping pressure solution seams are passively rotated to dip subvertically near the bedding plane of a steeply inclined sandstone bed.

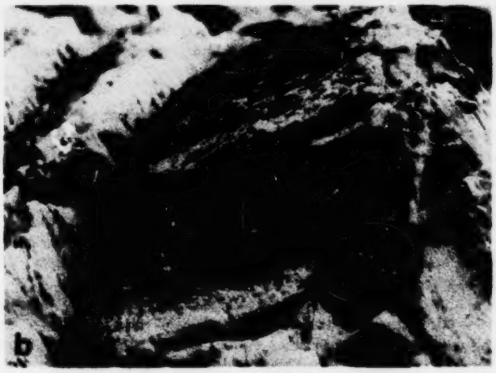


Figure 14b. Vertical pressure solution seams subparallel to bedding displace moderately dipping, passively rotated pressure solution seams.

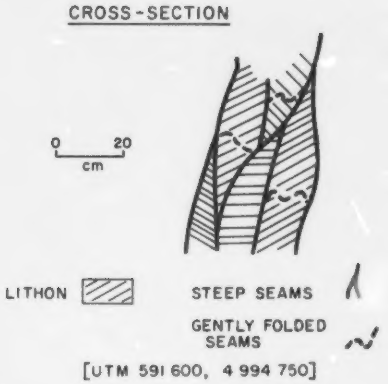
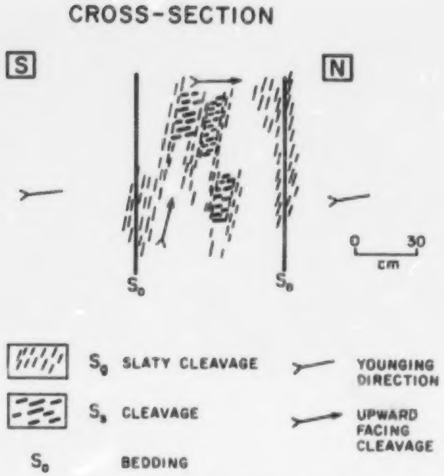


Figure 15. A relationship between moderately dipping, gently folded pressure solution seams and steeply dipping, anastomosing pressure solution seams.

The orientation of the slaty cleavage is notably consistent, especially when compared to the pressure solution cleavage. It is uncommon to find evidence for passive rotation. Slaty cleavage dips between 80° and 90° everywhere and generally strikes east-west varying between 085° and 105° (Fig. 17). In plan, the strike of slaty cleavage lies very close to that of bedding and the axial trace of major folds. It is axial planar to most, but not all (e.g. Fig. 6) F_g minor folds.

In several locations, vertical S_g cleavage passes through shales into interbedded siltstones and sandstones where it ceases to be slaty and becomes a closely spaced, coarser grained, yet penetrative foliation. The latter fabric locally overprints the widely spaced, moderately dipping, pressure solution cleavage (Fig. 18). Since the early-formed, pressure solution stripes appear to track the early stages of D_g buckling, the above obervations apparently imply that slaty cleavage formed relatively late in the D_g deformation. The local transection and shearing of F_s folds into east-west orientations and the concomitant development of F_g folds with nonaxial planar, slaty cleavage (Fig. 6) further supports this hypothesis.

The apparent time lag between the formation of the two varieties of S_g cleavage is probably the chief cause of the spectacular cleavage refraction in the Meguma Group. Approaching the bedding planes of thick sandstone beds, pressure solution cleavage is passively steepened and its strike is rotated in an attempt to align itself with the slaty cleavage in the interbedded shales. Both types of cleavage remain upward facing. Because pressure solution cleavage forms in sandstones and slaty cleavage forms in shales with opposing convergent and divergent fans, refraction must occur across beds of striking lithological contrast. Pressure solution cleavage is most intensely developed in Goldenville sandstones near the hinge zones of the major folds. There the stripes dip consistently vertical and have not been rotated. It seems that where upright, pressure solution stripes are axial planar to F_g folds they were produced at approximately the same time as the vertical, axial planar, slaty cleavage. The stereplot of poles to pressure solution stripes illustrates a wide range of orientations from those markedly oblique and noncoplanar to those subparallel to the mean slaty cleavage (Figs. 13 and 17). An important corollary of this observation is that folds which develop late in D_g only display subvertical S_g cleavage and do not yield evidence of passive D_g foliations.


CROSS-SECTION
S
N
S_0
S_0
0
30
cm
S_9 SLATY CLEAVAGE
YOUNGING DIRECTION
S_8 CLEAVAGE
UPWARD FACING CLEAVAGE
S_0
BEDDING

[UTM 612 850, 4 996 000]

Figure 16. Schematic field sketch illustrating the incomplete transpositon of S_8 cleavage by S_9 cleavage.

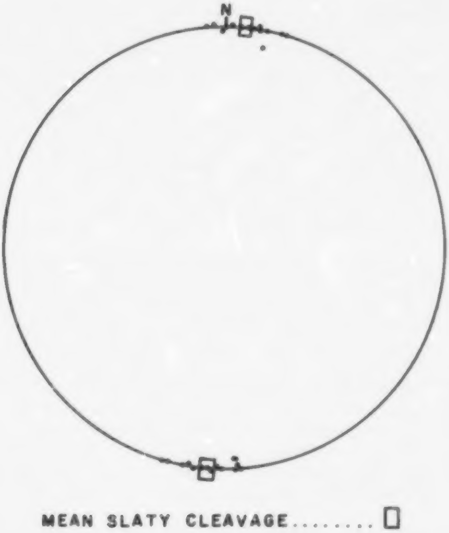


Figure 17. Stereoplot of poles to slaty cleavage from the core and both limbs of the Wine Harbour Anticline at Indian Harbour. Total of 16 different measuremants taken.

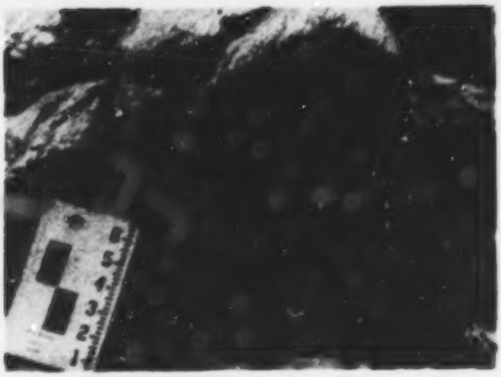


Figure 18. Widely spaced, moderately dipping, pressure solution seams in a vertical sandtone bed crossed by a later, closer spaced, steeply dipping foliation.

In places, the imposition of vertical S_9 cleavage produced infolding of the bedding planes separating shales and sandstones (Fig. 19). Such folds are extremely irregular in shape and essentially reflect the viscosity contrast between shale and sandstone (e.g. Ramberg, 1968). They vary from open, polyclinal structures to upright cuspate isoclines, yet given a sufficiently large exposure, the folded bedding planes are seen to dip gently. These D_9 minor structures may have regional significance as published cross-sections of the boundary between the Halifax and Goldenville Formations illustrate very similar fold shapes (Fletcher and Faribault, 1911; Fig. 20). In the area surveyed it is quite possible that, prior to late D_9, slaty cleavage-related shortening, an enveloping surface drawn on the Halifax-Goldenville contact would have been regionally flat. Late D_9, cleavage-related deformation may be responsible for tightening the major folds, particularly in their hinge zones.

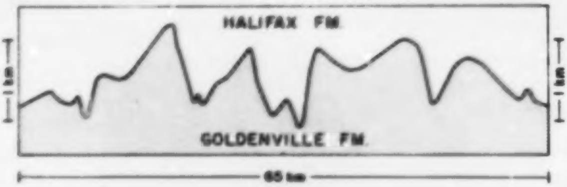
FOLDS

Minor F_9 folds are outlined by cleavage, by quartz veins and by bedding. Whereas folds of cleavage are commonplace, those of bedding are rare. Minor F_9 folds of grain alignment cleavage, pressure solution cleavage and discordant quartz veins occur within beds that are not locally folded (Figs. 12, 21).

Gently plunging F_9 folds of S_8 cleavage are normally open in the centre of massive, subvertical sandstone beds (Fig. 22). In places, however, isoclinal, cuspate folds occur within trains of the open, F_9 minor folds. Since the lithology, texture and grain size of the beds and the folded cleavage are constant, such changes in fold shape probably relate to local variation in the incremental strain.

Small scale F_9 folds of S_8 cleavage provide important information about large scale, buckle folding during D_9. As a general rule,

Figure 19. Gently dipping bedding plane between sandstone and shale shortened to produce variably shaped folds. Vertical pressure solution and slaty cleavages are attendant to the infolds of sandstone in shale and shale in sandstone respectively.



MODIFIED FROM
FLETCHER AND FARIBAULT (1911)

Figure 20. Cross-sectional shape of the regional folds of the contact between the Halifax and Goldenville Formations.

the bedding planes between sandstones and shales contain the hinge lines of distinctly asymmetrical, gently plunging, F_g step folds of S_s (Fig. 21). This type of fold is also defined by those quartz veins historically referred to as "flat angulars" (e.g. see Rickard, 1912). In Figure 21 it appears that the bedding planes are shear planes. The sense of displacement of S_s cleavage and quartz veins across bedding planes is such that it results in the shearing of younger beds upwards over older beds. This probably implies that buckle folding proceeded in some places by a flexural slip mechanism. Significantly, the sense of F_g vergence obtained from the fold shape of S_s cleavage and quartz veins opposes that obtained from the intersection of slaty cleavage and bedding (Fig. 21).

Certain beds continued to buckle by flexural slip after the imposition of vertical S_g cleavage. In several localities, vertical S_g

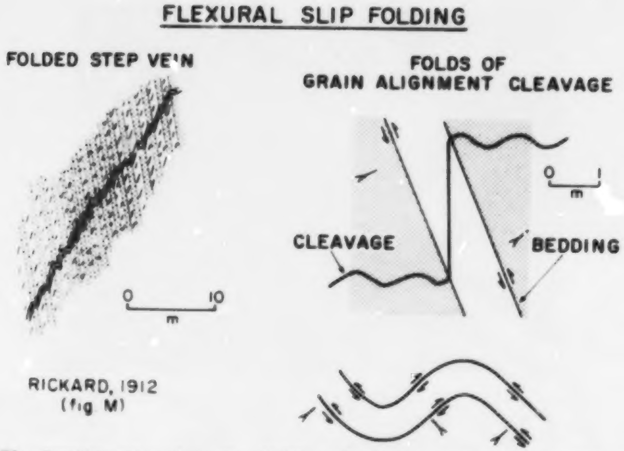

FLEXURAL SLIP FOLDING
FOLDED STEP VEIN
0
10
m
RICKARD, 1912
(fig. M)
FOLDS OF
GRAIN ALIGNMENT CLEAVAGE
0
1
m
CLEAVAGE
BEDDING

Figure 21. Gently plunging F_g folds of "flat angular" quartz veins and S_s grain alignment cleavage in right-way-up, stratigraphical successions of sandstones (dotted) and shales (dashed). The characteristic step shape of the folds results from the shearing of younger beds upwards over older beds and points to a probable flexural slip mechanism.

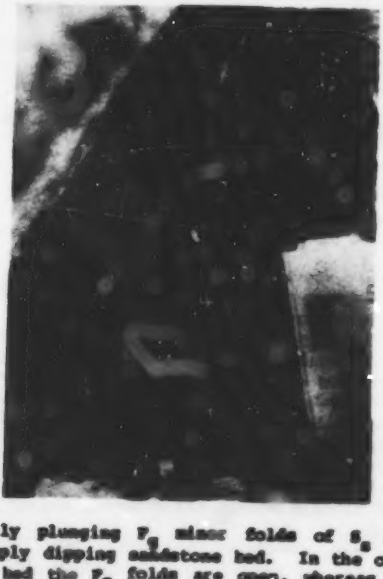


Figure 22. Gently plunging F_g minor folds of S_s cleavage in a steeply dipping sandstone bed. In the central part of the bed the F_g folds are open, whereas near the bedding plane they are tighter.

pressure solution stripes, S_s cleavage and steeply dipping, east-west joints are drag folded into moderately dipping attitudes by shear along bedding planes (Fig. 23). Gently dipping shear joints are slightly steeper than bedding and are spatially associated with rocks which display the rotation of the vertical cleavage stripes (Fig. 24).

In other locations, minor F_g fold structures indicate that buckling may have occurred by neutral surface folding. In gently dipping rocks near the hinges of some of the major folds S_s cleavage is folded from original, gently dipping orientations near the bedding planes to subvertical attitudes near the centre of the beds (Fig. 25). However, S_s is not steepened everywhere between the bedding planes. Despite the occurrence of distorted grain alignment cleavage in overlying and underlying strata, D_g shortening of S_s is apparently confined to the upper part of a single bed. This phenomenon can be best explained by the presence of an intrastratal neutral surface, locally above which a synclinally folded bed is in D_g compression and below which it is in D_g extension (Fig. 25).

Minor F_g folds defined by bedding are rarely found and they are nowhere associated with the F_g folds of the S_s and S_g cleavages. Beds are seen to be locally folded by (i) open to close, parallel folds, and by (ii) isoclinal similar folds. Minor and mesoscopic, gently plunging parallel folds are uncommon. They occur in gently dipping strata near the hinge zones of the major folds and have large interlimb angles, long wavelengths and shallow amplitudes. In a few places, small scale step and box folds interrupt the trains of parallel folds. Vertical slaty cleavage is approximately parallel to the axial surface of the F_g parallel folds, but lies at a large angle to the axial surface of the F_g asymmetrical folds. Such fold trains may have developed in flat or gently inclined strata near the hinges of regional scale, buckle folds subsequent to D_s and early D_g deformation.

Minor F_g isoclinal folds of bedding are observed sporadically in narrow zones ranging from 1 m to 5 m in width. These zones have been recognized on the limbs and in the cores of the major folds. They always separate unrepeated, right-way-up beds illustrating D_s and early D_g minor structures. The isoclines commonly occur in thinly bedded, shale-sandstone sequences and are overlain and underlain by prominent, massive sandstones. Vertical, axial planar, slaty cleavage is normally well developed. On the major fold limbs isoclinal fold trains show S- or Z-senses of vergence, while in the cores they illustrate M- or W-shapes. Figure 26 illustrates an example from the hinge zone of a regional anticline. F_g isoclines of bedding formed before or synchronously with slaty cleavage and, therefore, record late D_g increments of relatively large strain. The isoclinal minor folds were probably superimposed on larger buckle folds since there is no evidence to suggest that they represent flattened open folds. As the major F_g folds tightened during inhomogeneous, progressive D_g deformation, large parts of the folds acted as stable buttresses. Between these buttresses relatively intense, late D_g deformation produced narrow zones of gently plunging, isoclinal folds in small internally repeated successions of the Meguma Group.

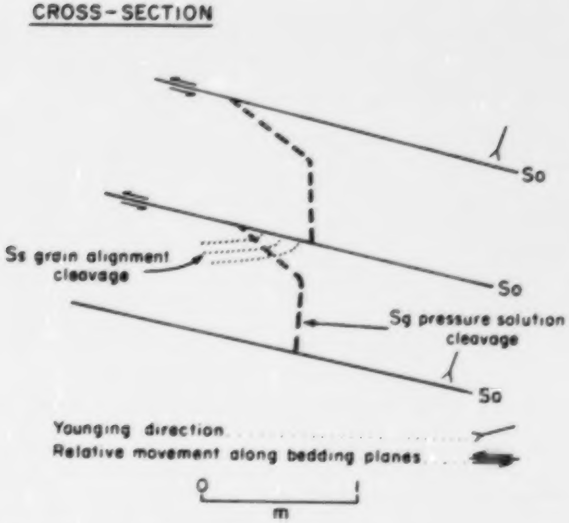

CROSS-SECTION
So
So
So
Ss grain alignment cleavage
Sg pressure solution cleavage
Younging direction
Relative movement along bedding planes
0
1
m

Figure 23. Shear along bedding planes during late stage flexural slip movements drag folded the vertical S_g pressure solution seams into moderately dipping attitudes near the tops of certain sandstone beds.

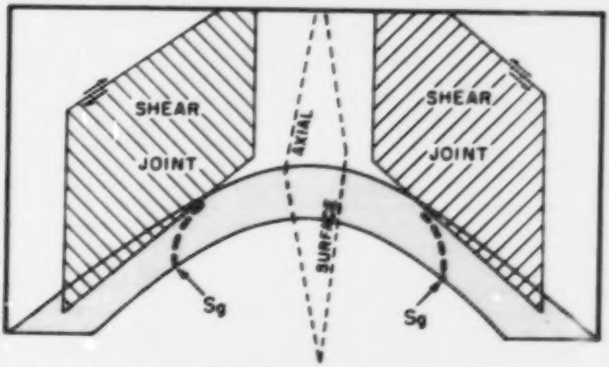

SHEAR
JOINT
SHEAR
JOINT
AXIAL
SURFACE
Sg
Sg

Figure 24. Gently dipping shear joints, slightly steeper than bedding, developed during late stage flexural slip folding and are spatially associated with drag folded, pressure solution seams (S_g).

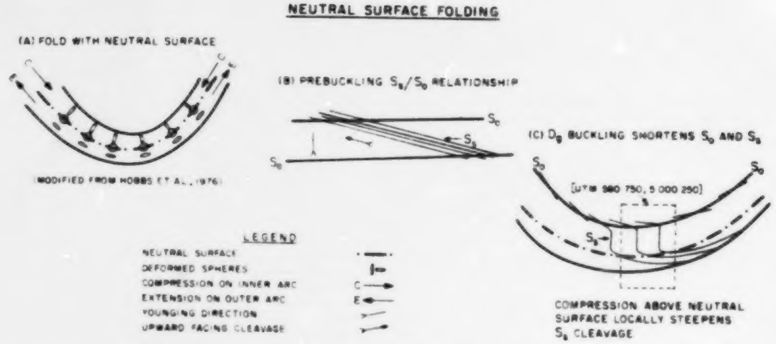

NEUTRAL SURFACE FOLDING
(A) FOLD WITH NEUTRAL SURFACE
C
E
(MODIFIED FROM HOBBS ET AL., 1976)
(B) PREBUCKLING S_8/S_0 RELATIONSHIP
S_0
S_8
(C) D_8 BUCKLING SHORTENS S_0 AND S_8
[UTM 580 750, 5 000 250]
COMPRESSION ABOVE NEUTRAL SURFACE LOCALLY STEEPENS S_8 CLEAVAGE
LEGEND
NEUTRAL SURFACE
DEFORMED SPHERES
COMPRESSION ON INNER ARC
EXTENSION ON OUTER ARC
YOUNGING DIRECTION
UPWARD FACING CLEAVAGE

Figure 25. Compression above an intrastratal neutral surface on the inner arc of a syncline causes shortening and steepening of the gently dipping S_8 grain alignment cleavage.

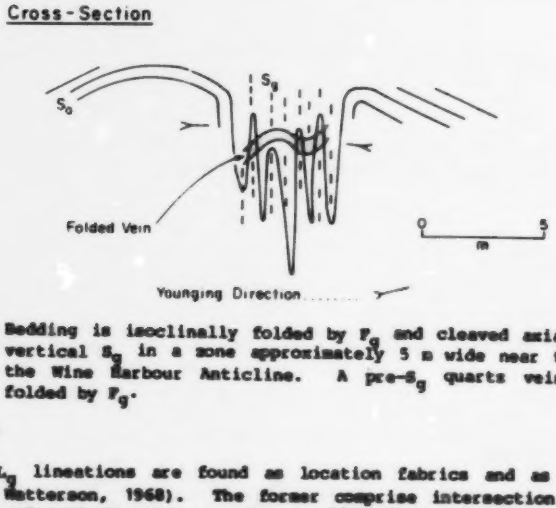

Cross-Section
S_g
S_0
Folded Vein
0
5
m
Younging Direction

Figure 26. Bedding is isoclinally folded by F_g and cleaved axial planar by vertical S_g in a zone approximately 5 m wide near the hinge of the Wine Harbour Anticline. A pre-S_g quartz vein is openly folded by F_g.

LINEATIONS

L_g lineations are found as location fabrics and as shape fabrics (cf. Watterson, 1968). The former comprise intersection lineations and single mineral lineations. The L_g lineations, formed by the intersection of pressure solution cleavage and bedding, have trends which contrast with those formed by the intersection of slaty cleavage and bedding. The former commonly trend oblique to the generally east-west axial traces of the major folds and pitch moderately on S_0, whilst the latter trend approximately parallel to the axial trace and pitch gently on S_0 (Fig. 27). The L_g lineations are doubly plunging because the major folds are periclinal. The trace of intersection lineations on bedding planes is com-

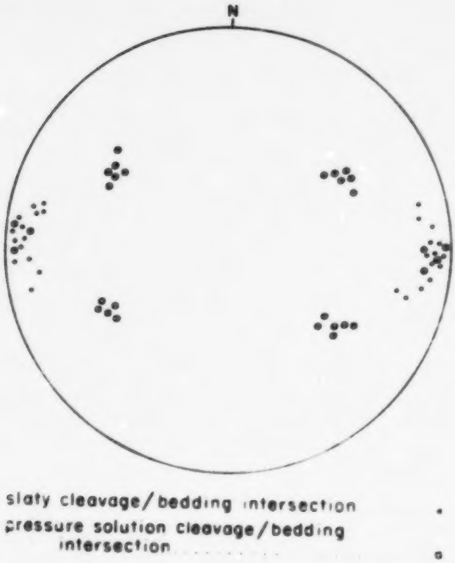


Figure 27. Stereoplot of poles to L_9 intersection lineations. Total of 60 measurements taken.

monly parallel to ripple crests and flute casts giving them a strikingly linear appearance. Where east-west trending strata are isoclinally folded, the intersection of bedding on upright slaty cleavage produces a L_9 lineation with subhorizontal, east-west plunge. Where major F_9 folds are open, intersection lineations on slaty cleavage are also gently plunging and east-west trending. This remains the case even where the dip directions of S_0 and S_8 are highly discordant to the L_9 orientation (Fig. 28). There does not appear to have been any change in the attitude of intersection lineations with time or with increasing deformation. Mafic crystals in calc-silicates define excellent mineral lineations in rocks illustrating L>S fabrics. This type of L_9 lineation is also observed to plunge gently, east-west.

Objects such as sand volcanoes are markedly elliptical on bedding planes and cleavage surfaces. In the area surveyed, L_9 lineations defined by the long axes of shape fabrics are everywhere gently plunging approximately parallel to the F_9 fold axes. During D_8 shearing and D_9 flexural slip the bedding planes were likely surfaces of no finite strain and, therefore, objects on these planes would not have changed from their original shape. Sand volcanoes are, nevertheless, elongated on the surfaces of beds and their long axes are parallel with the trace of S_9 cleavage. LS-shape fabrics seen in the plane of the vertical mineral fab-

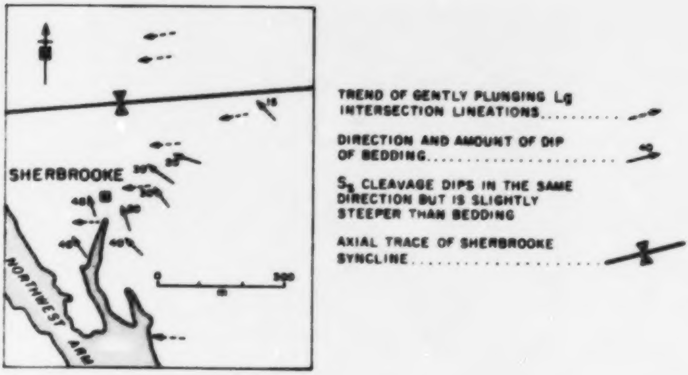

SHERBROOKE
NORTHWEST ARM
0
300
m
TREND OF GENTLY PLUNGING Lg INTERSECTION LINEATIONS
DIRECTION AND AMOUNT OF DIP OF BEDDING
S_s CLEAVAGE DIPS IN THE SAME DIRECTION BUT IS SLIGHTLY STEEPER THAN BEDDING
AXIAL TRACE OF SHERBROOKE SYNCLINE

Figure 28. Structural sketch map illustrating representative orientations of S_o and L_g in the vicinity of the Sherbrooke Syncline.

ric have their L-component pitching gently. Assuming that the observed shapes are not resultant and that they approximate to a cleavage-related, incremental strain ellipsoid, then the L_g shape fabrics indicate an extension in late D_g parallel to the subhorizontal fold axes. Because of the contrast in lithology across bedding planes containing elliptical objects and the presence of strong S_g cleavage near these objects, calculations of the amount of extension yield minimum estimates.

The Country Harbour Deformation

Minor structures formed during the Country Harbour deformation include cleavage, a related lineation and, less commonly, folds. D_c deformation affected the entire area but D_c minor structures have an irregular, regional distribution. The coast section along the western shore of Country Harbour illustrates the characteristic style of D_c exceptionally well.

Cleavage

S_c cleavage is a variably penetrative, crenulation cleavage (Fig. 29). Typically, it has a gentle dip and strikes generally east-west parallel to the regional grain (Fig. 30). Because S_c cleavage formed after F_s and F_g folding, it locally occurs with the same shallow dip in both gently and steeply inclined beds. In steep rocks S_c makes a large angle with S_o, while in flat rocks a small angle intersection is observed. This feature is, of course, also characteristic of the S_s cleavage. Subhorizontal S_c and S_s foliations have different morphologies, but they are fundamentally distinguished by their individual relation to S_g. S_c crenulates S_g, while S_s is overprinted by S_g (Fig. 31).

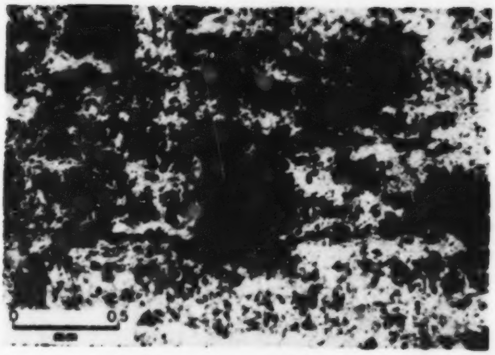


Figure 29a. Discrete, spaced S_c cleavage zones separating areas of crenulated S_g cleavage. The latter forms curved inclusion trails in biotite porphyroblasts. Plane light.

Figure 29b. Gently dipping downward facing S_c crenulation cleavage is the pervasive foliation throughout most of the shale bed. It is not developed in the stratigraphically underlying sandstone bed. Steeply dipping, upward-facing S_g slaty cleavage is observed in the bottom 5 cm of the shale and transects the bedding plane between the shale and the sandstone.

S_c crenulation cleavage developed selectively in certain shale beds (Fig. 32). Here S_s and S_g are commonly transposed by S_c, although bedding planes are rarely affected. Interbedded sandstones display D_s and D_g structures. Where S_c cleavage is particularly strong, it is observed to be banded. Dark coloured layers are composed of blocky, biotite porphyroblasts (Fig. 29) which are not aligned dimensionally, but yet show a preferred crystallographic orientation (G. Muecke, personal communication, 1982). The basal green beds of the Halifax Formation are

Figure 29c. Penetrative S_c cleavage illustrating dark bands composed largely of blocky biotites.

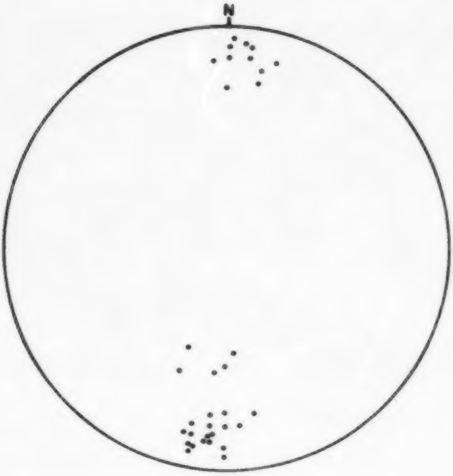


Figure 30. Stereoplot of poles to S_c crenulation cleavage. Total of 35 measurements taken.

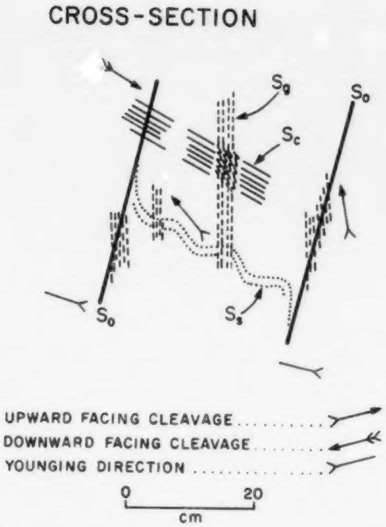

CROSS-SECTION
Sg
So
Sc
So
Ss
UPWARD FACING CLEAVAGE
DOWNWARD FACING CLEAVAGE
YOUNGING DIRECTION
0
20
cm

Figure 31. Geometrical relationships of S_o, S_s, S_g and S_c. The bed is right-way-up.

Figure 32. Gently dipping S_c crenulation cleavage is developed selectively in shales, where it is locally the pervasive foliation. It is not present in the interbedded sandstones.

locally transposed by S_c for at least 15 m above the contact with the Goldenville Formation at Fishermans Harbour. Elsewhere in the same beds, less penetrative S_c cleavage crosses the axial surfaces of minor F_g isoclinal folds. Cleavage of D_c age generally provides an upper limit on the development of tectonic structures. It has been used in the synclines cored by the Halifax Formation to show that the most intense deformation predates S_c.

In right-way-up beds on the limbs of the major folds S_c cleavage is normally seen to be variably facing (Fig. 33). This is due to the fact that S_c dips to the north and south across a consistently orientated, stratigraphical succession. The distribution of areas of predominantly northerly dipping and predominantly southerly dipping, S_c cleavage is apparently random (Fig. 34). It does not relate to the presence or absence of F_g folds, but there is a tendency for certain dip directions on given fold limbs. Dips of S_c vary from 45°S to 35°N, although there are few horizontal measurements (Fig. 30). It is doubtful that this phenomenon is an original feature, e.g. there are no exposures of mutually displacive, S_c conjugate cleavages. There may be map scale distortion of a regionally flat foliation by post-S_c deformation. In the area surveyed, S_c crenulation cleavage is not seen to be locally folded or overprinted by later fabrics, at least on the scale on which it is observed (see however Keppie, this volume).

FOLDS AND LINEATIONS

F_c minor folds are not as common as S_c cleavage but, where they are seen together, the crenulation cleavage is axial planar to the folds. Subrecumbent F_c folds are open to close and gently plunging.

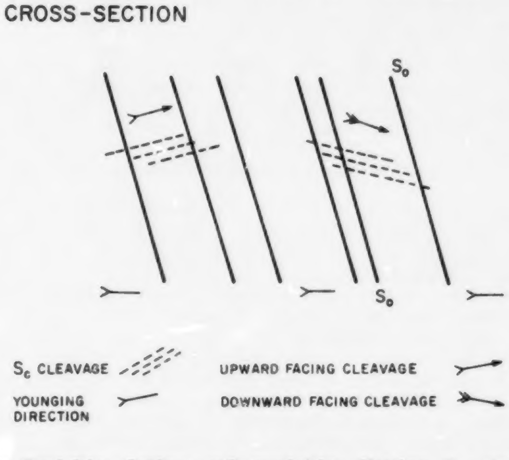
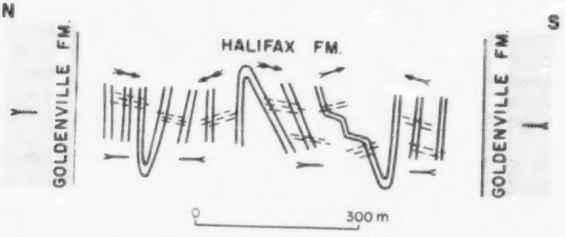


Figure 33. Variably facing and variably dipping S_c crenulation cleavage occurring in a right-way-up, stratigraphical succession of beds.



HALIFAX FM. IN W-SHAPED SYNCLINORIUM
ON THE ST. MARYS RIVER

Figure 34. S_c crenulation cleavage transects F_g folds in the Halifax Formation. Alternating northern and southern dipping S_c cleavages both face upwards (single forked arrows) and downwards (double forked arrows) in right-way-up beds. Changes in the dip and facing directions of S_c are apparently not controlled by the presence or the shape of the F_g folds.

They commonly fold subvertical S_g cleavage but rarely bedding. F_c folds are superimposed coaxially on larger F_g folds; interference patterns are not produced. Rocks that have been severely boudinaged or necked are also found to display numerous F_c folds. F_c axial surfaces dip to the north and south. Since F_c folds do not show a regionally consistent sense of overturning, it can be probably concluded that there is no preferred direction of D_c translation.

For the most part L_c lineations are gently plunging, east-west trending intersection lineations. In places, small F_c fold hinges form pucker or pyllitic lineations (Fig. 35). L_c is mostly seen on the surface of steep, slaty cleavage.

Age of Minor Structures

Features of D_s, D_g and D_c deformations are present in the Halifax and the Goldenville Formations. The Halifax Formation has yielded Tremadocian fossils (Taylor, 1969). The post-tectonic Sherbrooke pluton (Fig. 1) was intruded after the D_c deformation and has been dated at 369±2 Ma (Smith, this volume). The D_s-D_c structures were formed sometime between the Lower Ordovician and the Middle Devonian and most probably result from the Acadian Orogeny.

Other Deformations

There are minor structures affecting vertical S_g cleavage that may be either pre-D_c or post-D_c in age. Some are ductile structures such as folds, crenulations and boudins; others are brittle and include joints, small faults and kink-related structures.

Figure 35. Minor F_c fold hinges form gently plunging, pucker or phyllitic lineations.

The most common ductile structures are boudins and cross folds. In many locations they are seen to be spatially associated. The long axes of boudinaged quartz veins plunge in several directions subhorizontally and subvertically. Slaty cleavage is also affected. This possibly implies that post-S_g extension occurred equally in all directions. Open crenulations are related to reclined folds trending across the major axial traces (e.g. Fyson, 1966). They are preferentially developed near the neck line of en echelon boudins (Fig. 36). Compression and extension related to one progressive deformation may have produced the crenulation and the boudins respectively.

In localized areas, particularly near steeply dipping quartz veins embedded in shale, subvertical slaty cleavage is folded by gently plunging folds with upright to inclined axial surfaces. Their relation to F_c folds with axial planar S_c cleavage was not observed. Outside the area mapped in the Mount Uniacke gold camp such folds are seen to span the development of subvertical S_g cleavage. Slaty cleavage may have been produced over a period of time like the pressure solution stripes; in this case, late rather than early in D_g.

In exposures along the St. Marys River south of Sherbrooke, a sporadic but locally penetrative crenulation cleavage deforms S_g cleavage. It has a shallow dip like S_c but strikes north-northeast to south-southwest. A D_c age for this cleavage is problematical since it is oriented noncoaxially with respect to the local D_g structures.

Widespread joints, faults and kink bands are presumably related because one can be seen to pass into another. One of the major arrays of quartz veins in the Meguma Group are emplaced along these structures (O'Brien, 1982). The joints are oriented parallel and oblique to the S_g cleavage and the axial traces of the major folds (Fig. 37). They include

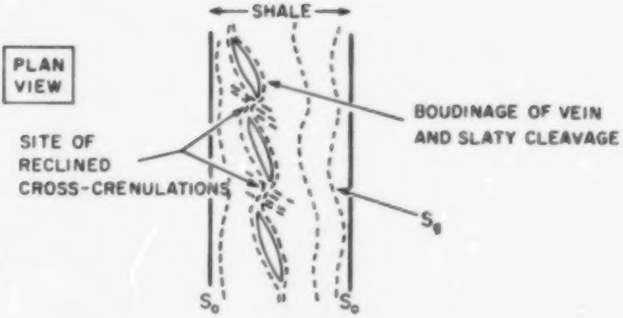

SHALE
PLAN VIEW
BOUDINAGE OF VEIN AND SLATY CLEAVAGE
SITE OF RECLINED CROSS-CRENULATIONS
S_g
S_0
S_0

Figure 36. Reclined cross crenulations spatially associated with the neck line of en echelon boudins. Note that the slaty cleavage and the quartz vein are boundinaged. Right lateral shear along the slaty cleavage could have produced the right hand en echelon boudins and crenulations lying anticlockwise of S_g.

both steep and shallow sets of conjugate shear joints in addition to the more commonly encountered ac- and bc-joints. In places, the steep shear joints are associated with sigmoidal, en echelon veins filled by fibrous quartz (Fig. 38). The geometry of the fibres indicates that subhorizontal west-northwest to east-southeast and east-northeast to west-southwest extension occurred in steep-sided shear zones. The principal shear planes are coincident with the conjugate shear joints. Although the ac- and bc-joints may have originated as tensile fractures set in a field of shear fractures (Fig. 39), they themselves subsequently become planes of shear and offset (Fig. 40). Slickensides on the surface of vein quartz filling ac- and bc-joints are subhorizontal.

Minor faults, locally containing gouge, are found trending in four prominent directions: east-west, northwest-southeast, northeast-southwest and north-south.

MAJOR STRUCTURES

In the area between Gegogan Harbour and Country Harbour there are seven major folds and at least three major faults (Fig. 1). The axial traces of the tight to isoclinal St. Marys Bay and Sonora Synclines occur within the outcrop of the Halifax Formation (CO_H), and the trace of the open to close Sherbrooke Syncline lies within the Goldenville Formation (CO_G). The Gegogan, Wine Harbour, Goldenville and Stillwater Anticlines are all observed within the latter Formation. Several past-producing gold mines are located in steeply dipping Goldenville strata near the crests of some of these Anticlines. The Indian Harbour, Country Harbour and Quinces Brook Faults displace the axial trace of some of the major folds (Fig. 1A).

In Figure 41 the major folds are shown in cross-section. The dispositon of representative minor structures on the major folds is also

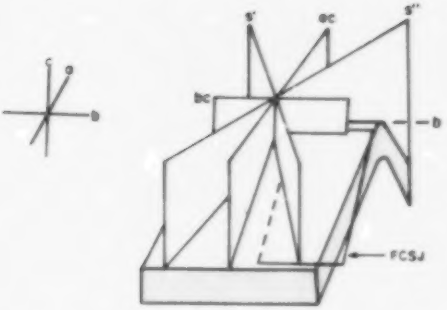

s'
ac
s''
c
a
b
bc
b
FCSJ

Figure 37. The relative orientations of ac-joints, bc-joints, flat conjugate shear joints (FCSJ) and steep conjugate shear joints (S' and S").

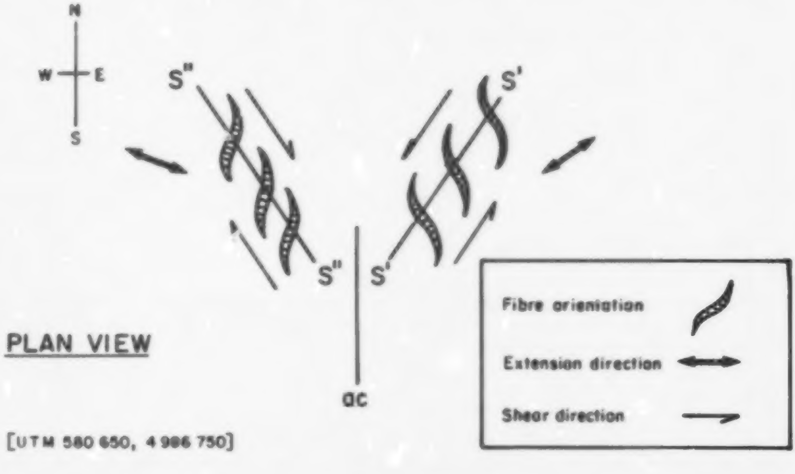

N
W
E
S
S"
S'
S"
S'
PLAN VIEW
ac
Fibre orieniation
Extension direction
Shear direction
[UTM 580 650, 4 986 750]

Figure 38. Geometrical relation of sigmoidal fibre-filled quartz veins to the steep shear joints. The quartz fibre orientations in the veins indicate the extension directions in conjugate shear zones, the principal planes of which are parallel to the shear joints. Extension directions in the conjugate shears are approximately perpendicular and lie clockwise and anticlockwise of the ac-joints.

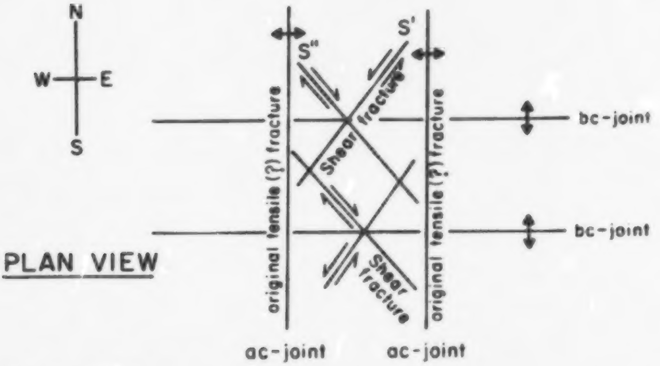

N
W
E
S
PLAN VIEW
S"
S'
original tensile (?) fracture
original tensile (?) fracture
Shear fracture
Shear fracture
bc-joint
bc-joint
ac-joint
ac-joint

Figure 39. Geometrical relationship between the ac- and bc-joints (tensile fractures?) and the steep, conjugate shear joints (shear fractures) in plan view.

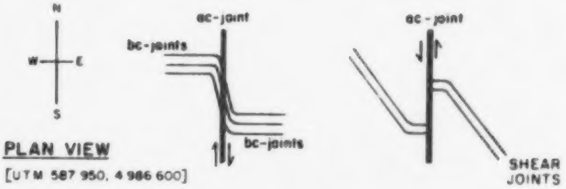

N
W
E
S
PLAN VIEW
[UTM 587 950, 4 986 600]
ac-joint
bc-joints
bc-joints
ac - joint
SHEAR JOINTS

Figure 40. Shearing along ac-joints is variably dextral and sinistral. The time of shear relative to movements on the shear joints is presently unknown.

indicated. The D_s-D_c deformations are superimposed coaxially and, unlike other regions of multiphase deformation, major folds are not produced by each of F_s, F_g and F_c. This results in a lithological map which does not display regional fold interference patterns. The simplicity of the major folds appears to be in sharp contrast with the complexity of the minor structures. It is the writer's contention, however, that one group of major folds evolved over a considerable period of time and that the variation in their present cross-sectional shape reflects the different effects of D_s, D_g and D_c deformation. In general, sandstones in the hinges of the major folds record late increments of deformation, while sandstones on the fold limbs preserve the early increments. Where major fold cores are tight to isoclinal, S_g is strong and upright. Where they are open, S_g is sporadically present.

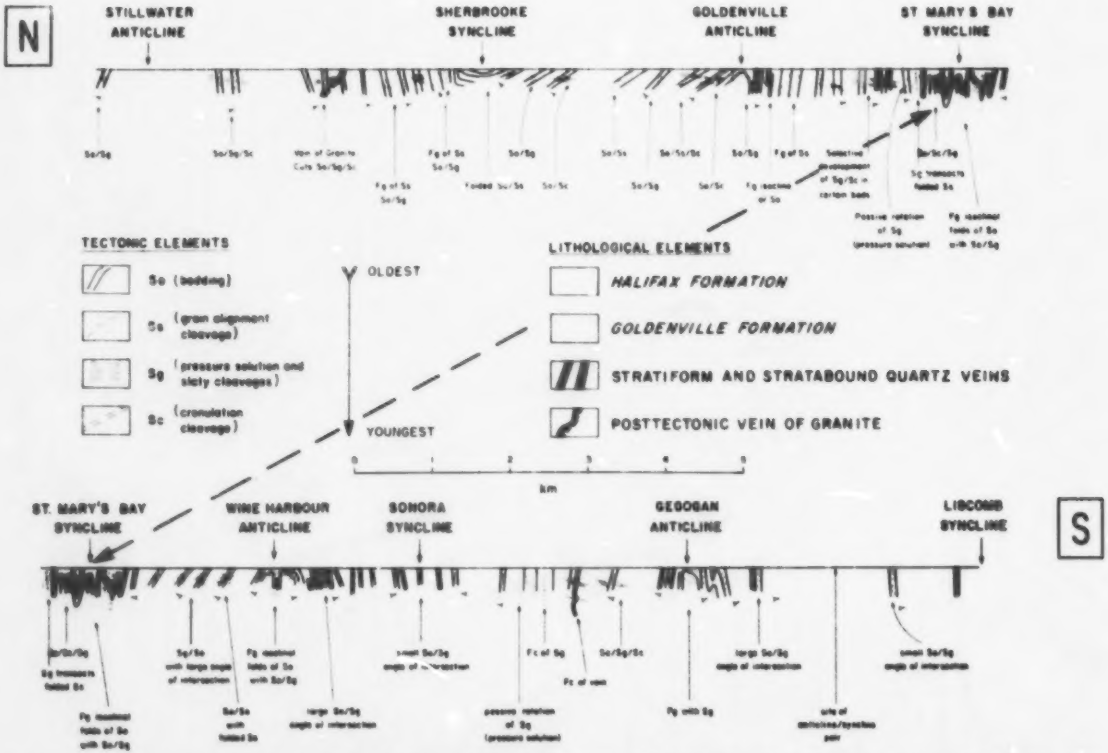

N
STILLWATER ANTICLINE
SHERBROOKE SYNCLINE
GOLDENVILLE ANTICLINE
ST MARY'S BAY SYNCLINE
So/Sg
So/Sg/Sc
Vein of Granite Cuts So/Sg/Sc
Fg of So So/Sg
Fg of So So/Sg
Folded So/Ss
So/Sg
So/Sc
So/Ss
So/Sg
So/Ss/Sc
So/Sc
So/Sg
Fg isoclinal of So
Fg of So
Selective development of Sg/Sc in certain beds
Passive rotation of Sg (pressure solution)
So/Sc/Sg
Sg transects folded So
Fg isoclinal folds of So with So/Sg
TECTONIC ELEMENTS
So (bedding)
Ss (grain alignment cleavage)
Sg (pressure solution and slaty cleavages)
Sc (crenulation cleavage)
OLDEST
YOUNGEST
LITHOLOGICAL ELEMENTS
HALIFAX FORMATION
GOLDENVILLE FORMATION
STRATIFORM AND STRATABOUND QUARTZ VEINS
POSTTECTONIC VEIN OF GRANITE
0
1
2
3
4
5
km
S
ST. MARY'S BAY SYNCLINE
WINE HARBOUR ANTICLINE
SONORA SYNCLINE
GEGOGAN ANTICLINE
LISCOMB SYNCLINE
So/Ss/Sg
Sg transects folded So
Fg isoclinal folds of So with So/Sg
Sg/So with large angle of intersection
So/So with folded So
Fg isoclinal folds of So with So/Sg
large So/Sg angle of intersection
small So/Sg angle of intersection
passive rotation of Sg (pressure solution)
Fc of Sg
Fc of vein
So/Sg/Sc
Fg with Sg
large So/Sg angle of intersection
axis of anticline/syncline pair
small So/Sg angle of intersection

Figure 41. Cross-section of the Meguma Group in the Gegogan Harbour-Country Harbour area. No horizontal exaggeration. Representative minor structures are shown on the major folds.

Rocks on the southern, gently dipping limb of the Sherbrooke Syncline show abundant, relatively unmodified D_s structures (Fig. 41). Moderate to gently dipping, northeast-southwest striking beds with subparallel S_s cleavage (Fig. 28) are transected by east-west trending S_g cleavage and L_g lineations. The S_o/S_s bedding-cleavage relationships on the northern, steeply dipping limb (Fig. 41) suggest that a large part of the succession may have been already steep prior to D_g, though it need not have been striking east-west at that time. An analogy may exist with the D_s fold structure depicted in Figure 6. Many of the asymmetrical, major folds show a tendency for the steep limb to deform differently than the shallow limb. This phenomenon is best visualised in a stereoplot of poles to bedding from the core and both limbs of a major fold. For example, measurements taken on the Wine Harbour Anticline illustrate that the poles from the northern and southern limbs cluster separately and that no single great circle can be drawn through the poles from both limbs (Fig. 42). Similarly, if the orientation of the major fold axis is determined by trying to approximate a best fit π-circle, then it is found that the β-pole maxima is not in agreement with the π-pole. Such observations are, however, in keeping with the notion that the present attitude of the beds does not solely result from F_g limb rotation. The asymmetry of the major folds may possibly be inherited from large scale F_s folds. During early D_g deformation areas of locally steep strata would likely form nucleation sites for the propogating F_g buckle folds (Fig. 3).

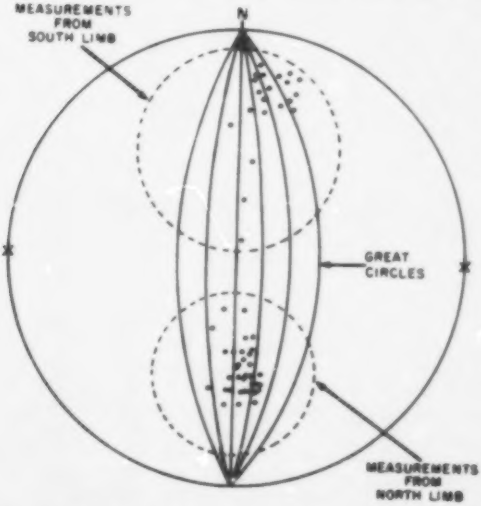


Figure 42. Stereplot of poles to bedding from the core and limbs of the Wine Harbour Anticline at Indian Harbour. A best fit π-circle drawn through measurements taken on the northern limb of the fold is not coincident with one obtained from measurements taken on the southern limb. The cross is the π-pole to a hypothetical east-west trending, upright fold.

Whereas the open to close Sherbrooke Syncline essentially records D_s and early D_g deformations, the tight to isoclinal St. Marys Bay and Sonora Synclines yield information about late D_g and D_c deformation. In the past, much significance has been given to the regional structures outlined by the lithostratigraphical contact between the Halifax and the Goldenville Formations. In the discussion of the minor structures it was pointed out that this boundary was sensitive to intense, localized deformation during D_g and D_c. In the area surveyed, the one-sided synforms of Halifax Formation were generally held to be upright and isoclinal (Faribault, 1893) simply because the basal contacts are approximately vertical and parallel (Fig. 41). Yet, on the St. Marys River, the St. Marys Bay Syncline is a polyclinal, W-shaped synclinorium (Fig. 34). Although most of the constituent folds are isoclinal, some are open. Here, S_c cleavage can be used to document the fact that the present fold morphology was largely established by the end of the D_g deformation.

Zones where bedding is isoclinally folded also occur near the hinges of many other major folds. For example, the Wine Harbour, Gegogan and Goldenville Anticlines display M-, and S-shaped fold trains (Fig. 41). In the case of the Wine Harbour Anticline, the presence of M-shaped folds may explain the reports of 'inverted saddles' in the underground mine workings. These narrow, intensely folded zones are inhomogeneously developed late in D_g. They modify the shape of the buckle folds significantly (Fig. 20). As a result, the major folds display changeable profiles along their axial traces and have irregular enveloping surfaces. Folds that appear to be regionally isoclinal have suffered relatively large amounts of shortening over small areas. It is suggested that the regional folds of the Halifax-Goldenville contact are locally modified, shallow amplitude-large wavelength structures.

Cross folds are mostly observed as minor and mesoscopic structures and then preferentially in areas where vertical S_g cleavage is notably strong. The regional effect of cross folding is best appreciated by mapping the trace of major folds with steeply dipping axial surfaces. For example, the axial trace of the Wine Harbour Anticline between the Indian Harbour and Country Harbour Faults (Fig. 1) is seen to be gently folded about steep fold axes.

Major faults in the Gegogan Harbour-Country Harbour area trend northwest-southeast and east-west. Smaller, northeast-southwest trending faults are observed but they do not appear to displace the axial traces of the major folds. Gouge containing randomly orientated fragments of slaty cleavage is present along the Quinces Brook Fault. Whereas the northwest-southeast trending faults are inclined to the major fold axes at a large angle, the east-west trending fault transects the Goldenville Anticline at a very small angle. The sense of displacement of the Quinces Brook Fault and its relation to the Indian Harbour and County Harbour Faults are unknown. From Figure 1, it is evident that the Sherbrooke pluton is emplaced through the Goldenville Anticline and the Sherbrooke Syncline and yet is itself displaced by the Indian Harbour Fault.

CONCLUSIONS

(1) Multiphase deformation of the Meguma Group occurred between the Lower Ordovician and the Middle Devonian and produced many structures typical of the slate belt association.

(2) The interbedded sandstones and shales of the Meguma Group behaved as a multilayer during D_s and D_g (O'Brien 1983). The D_s deformation caused a layer-parallel shear of variable intensity throughout at least 5 km of the multilayer. Bedding and stratiform quartz veins acted as both the principal planes of shear and anisotropy.

(3) Layer-parallel shortening gave rise to D_g buckling, which formed gently plunging, parallel folds in areas where the multilayer remained flat. Passively folded and steepened pressure solution stripes, quartz veins and grain alignment cleavage provide a record of most of the limb rotation during buckling.

(4) Subsequent to most but not all of the buckle folding and late in the episode of layer-parallel shortening, the steep slaty cleavage was imposed on all earlier folds. Cleavage-related flattening locally produced cuspate isoclines of the bedding. Objects in the plane of the steep foliation are typically extended subhorizontally parallel to the regional fold axes. The shearing of obliquely orientated F_s folds into the regional east-west grain occurred before or during the formation of the slaty cleavage.

(5) The Meguma Group ceased to behave as a multilayer after the beds acquired slaty cleavage. D_c minor structures commonly affect steep S_g cleavages but rarely deform bedding. Gravitational instability following inhomogeneous layer-parallel shortening probably caused the vertical collapse of the slate belt.

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TYPOMORPHISM OF TURBIDITE-HOSTED AURIFEROUS QUARTZ VEINS, SOUTHERN GUYSBOROUGH COUNTY*

S. J. Haynes

ABSTRACT

Field studies were concentrated in the greenschist facies Meguma Terrane of southern Guysborough County at Wine Harbour (chlorite zone) and Isaacs Harbour-Goldboro-Seal Harbour (biotite zone). Eleven different quartz-vein polytypes have been distinguished on the basis of form, characteristic mineralogy, wall rock alteration and crosscutting relationships to each other and regional structures. Visible gold is only present in stratiform, stratabound and side veins and as rare disseminations in the host rock slates. These predate the main period of Acadian deformation, dynamo-thermal metamorphism and granite intrusion. Most of the gold is contained within stratiform veins which exhibit crosslamination and columnar structures similar to modern geyserites observed in active geothermal areas. Gold is preferentially enriched in those zones where high angle K-feldspar ± muscovite bearing "feeders" (step and side veins) are abundant. These feeders often display marked arsenopyritization and/or sericitization of the wall rocks. The gold districts are preferentially located near the hinge zone of asymmetric Acadian folds. Although true "saddle reefs" are present, many vein systems are located on the limbs of folds often adjacent to monoclinal flexures. It is postulated that these monoclinal zones represent tectonic reactivation of original fault systems. The mineralogy and form of the veins, and their attendant wall rock alteration effects, suggest that gold was deposited initially from hydrothermal solutions, that passed upward through the fault systems, as they were ejected into seawater as low density plumes from submarine hot springs. This resulted in aprons of siliceous sinter being deposited at the spring orifices and a flanking mat of siliceous chemical sediment being deposited from the plume. Phase relations and the composition of fluid inclusions suggest that CO_2 boiled off from low-salinity hydrothermal solutions to yield potassium silicate assemblages in the feeders and carbonate assemblages in the sediments (stratiform veins). The origin of these solutions is as yet unknown, but may be related to dewatering of the lower Meguma Group or the basement. Although hydrothermal mobilization of gold and silica during early Acadian dynamo-thermic events cannot be discounted, syn-deformational quartz veins emplaced during the main period of Acadian deformation and metamorphism (discordant, radial and vertical veins) are devoid of gold. This casts doubt on those previous theories that invoked deposition of the auriferous quartz veins during Acadian dynamo-thermal metamorphism and deformation.

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*Contribution to Canada-Nova Scotia Co-operative Mineral Program 1981-84. Project carried by Nova Scotia Department of Mines and Energy and by Geological Survey of Canada.

INTRODUCTION

This report summarizes results obtained during the summer and fall of 1982 from detailed studies of the Wine Harbour and Isaacs Harbour-Goldboro-Seal Harbour gold districts (Fig. 1). Coastal sections were mapped at 1:100 scale over the Burke-North Star leads, Isaacs Harbour, and Barrachois Point, Wine Harbour; numerous pits and dumps were examined; two vertical shafts were cleared and sampled at the Mulgrave deposit, Goldboro; and a vein was cleared of large boulders and mapped at 1:30 scale at Crook Cove, Seal Harbour. Additional visits were made to Goldenville, Mount Uniacke, Beaverdam, Mile Lake, Forest Hill and Cochrane Hill.

The aim of this study was to characterize the form, mineralogy and structure of the different types of quartz-veins in order to determine their relationship to gold and their relative ages of emplacement.

Samples of quartz veins and host rocks were collected to determine vein and wall rock mineralogy, wall rock alteration effects, cleavage relations, metamorphic assemblages, elemental distribution and stable and radiogenic isotope values. Final results of the laboratory investigations will be available next year.

GEOLOGICAL SETTING

Host Rocks

Sedimentological aspects of the Goldenville Formation are reported in detail by Waldron (this volume).

The veins are hosted by psammites and slates of the Lower Paleozoic Goldenville Formation considered by Schenck (1970) and Waldron (this volume) to represent partial or complete Bouma turbidite sequences. Calcareous horizons, manganiferous lenses (Fig. 2) and lensoid pyrrhotiferous pods are often present in the psammitic units. Locally, pseudoporphyroblasts of arsenopyrite are abundant in the sediments (Figs. 3 and 4), sometimes associated with other sulphides. At the Victoria lead, Goldboro, crenulated wisps of native gold are disseminated in slate (Fig. 5).

Regional Structure

Regional structure is reported by Keppie and O'Brien (this volume) and the reader is referred to their reports.

The first event (D_s) appears to have been the development of F_s folds with attendant S_s cleavage, that is axial-planar to minor F_s folds in quartz veins (O'Brien, this volume). The main period of Acadian deformation (D_g) is marked by east-west trending, upright, essentially concentric, or asymmetric, cylindrical, noncylindrical, or conical, F_g folds (Keppie, this volume). Axial-planar S_g cleavages are present as pressure solution cleavage in psammites and slaty cleavage in pelites and semipelites. On fold limbs, at Isaacs Harbour, these two types of cleavage display consistently different attitudes to bedding: slaty cleavage dips in the same direction as bedding, whereas pressure solution cleavage dips

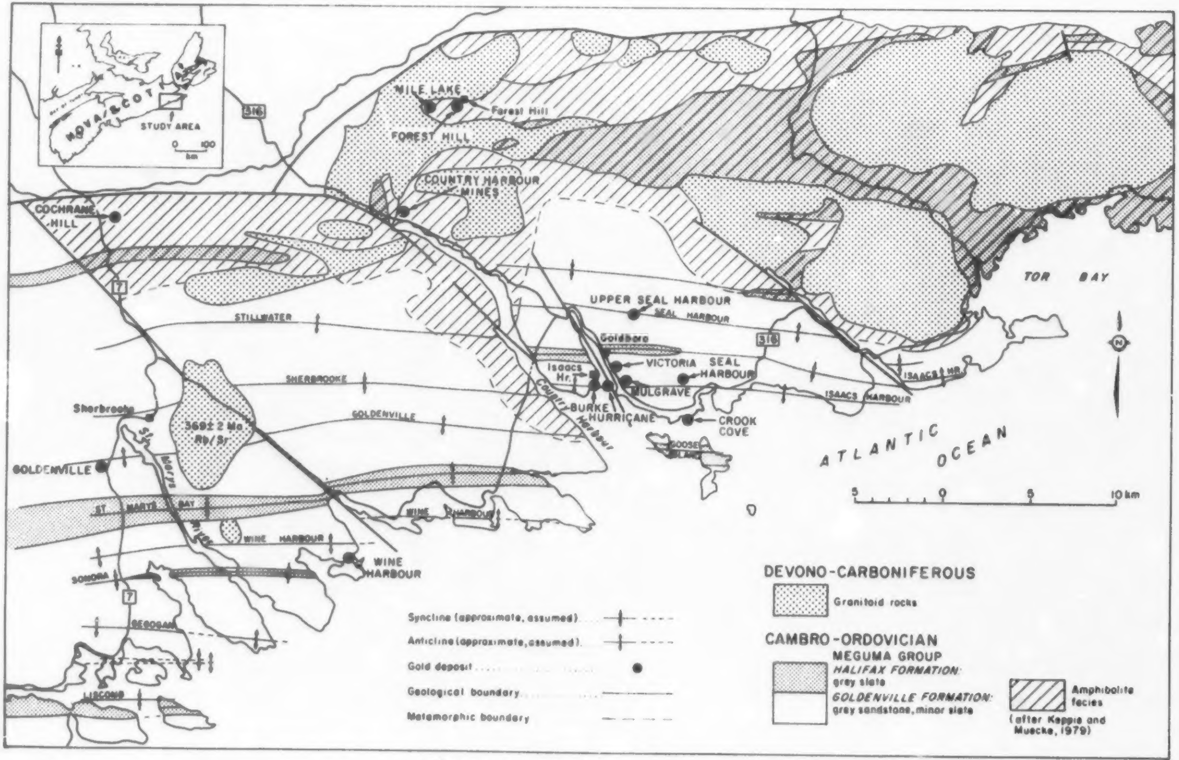

NOVA SCOTIA
STUDY AREA
0 100
km
516
NILE LAKE
Forest Hill
FOREST HILL
COUNTRY HARBOUR MINES
COCHRANE HILL
7
STILLWATER
SHERBROOKE
GOLDENVILLE
Sherbrooke
369±2 Ma Rb/Sr
St. Marys River
GOLDENVILLE
ST MARYS BAY
WINE HARBOUR
WINE HARBOUR
WINE HARBOUR
SONORA
SEGOGAN
LISCOMB
UPPER SEAL HARBOUR
SEAL HARBOUR
Goldboro
316
VICTORIA
SEAL HARBOUR
Isaacs Hr.
MULGRAVE
BURKE
HURRICANE
Country Harbour
CROOK COVE
GOOSE ISLAND
ISAACS HR.
ISAACS HARBOUR
TOR BAY
N
ATLANTIC OCEAN
5 0 5 10 km
Syncline (approximate, assumed)
Anticline (approximate, assumed)
Gold deposit
Geological boundary
Metamorphic boundary
DEVONO-CARBONIFEROUS
Granitoid rocks
CAMBRO-ORDOVICIAN
MEGUMA GROUP
HALIFAX FORMATION:
grey slate
GOLDENVILLE FORMATION:
grey sandstone, minor slate
Amphibolite facies
(after Keppie and Muecke, 1979)

Figure 1. Location map.

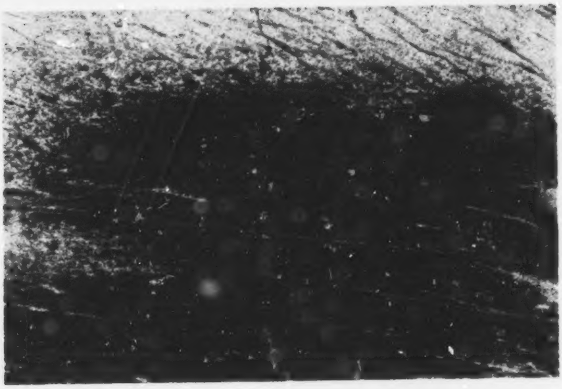


Figure 2. Manganiferous lens (dark) with calicte (light) at base of coarse psammite, Isaacs Harbour.

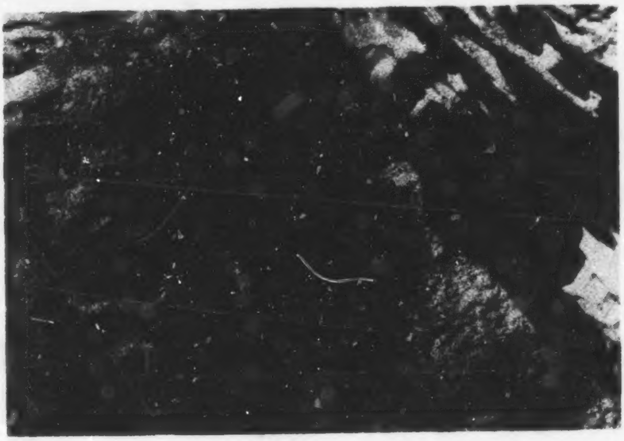


Figure 3. Pseudo-porphyroblast of arsenopyrite in psammite, Indian Harbour.

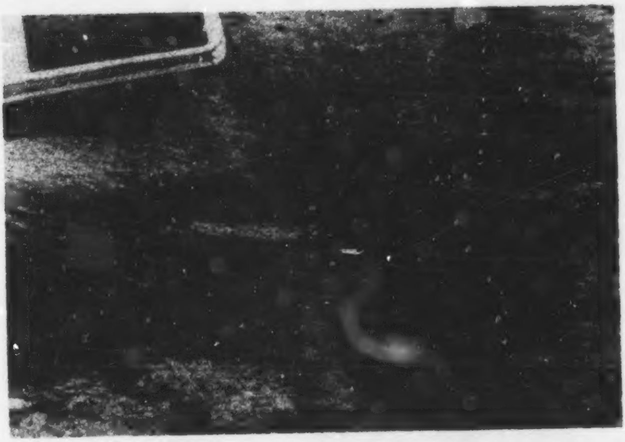


Figure 4. Pseudo-porphyroblast of arsenopyrite (black dots) in silt lens (white), slate bands, Wine Harbour.

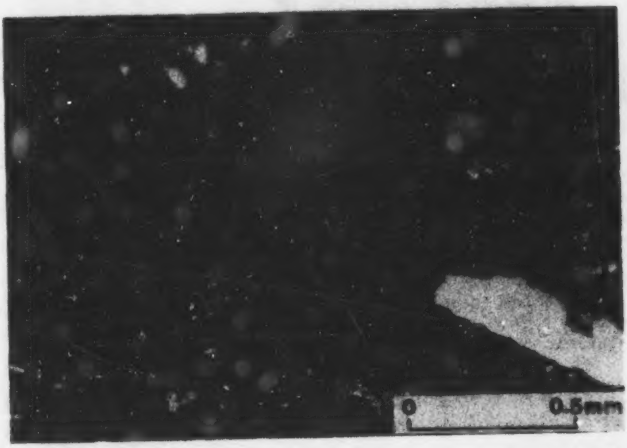


Figure 5. Wisps of gold (white, in centre of photograph) crenulated by F_g in slate, Victoria Mine, Goldboro.

in the opposite direction to bedding. Within upward-fining sequences, widely spaced pressure solution cleavage gradually rotates towards slaty cleavage and becomes closer-spaced, but across sharp pelite-psammite contacts slaty cleavage is abruptly refracted to pressure solution cleavage (Fig. 6). This "refraction" of axial planar cleavage has been observed in other greywacke terranes, e.g. Bermagui, Australia (Hobbs et al., 1976, p. 216).

Figure 6. Rotation of pressure solution cleavage in psammites and refraction of pressure solution cleavage to slaty cleavage across psammite-pelite boundaries, Isaacs Harbour.

In the Wine Harbour-Isaacs Harbour region, S_s and S_q are defined by muscovite and chlorite. These are deformed by a flat-lying S_c crenulation cleavage, also defined by muscovite and chlorite, axial planar to sporadic, F_c recumbent minor folds in quartz veins. These cleavages are overprinted by decussate growth of biotite porphyroblasts at Isaacs Harbour.

North of Isaacs Harbour, regional structures and metamorphism are more complex , involving late Acadian granitoid intrusion and post-Acadian dynamo-thermic events (see Keppie, and Smith, this volume).

QUARTZ VEIN TYPOMORPHISM

The quartz vein polytypes are distinguished on the basis of their form, characteristic mineralogy, wall rock alteration and their cross-cutting relationships to each other and regional structures (Table 1).

Stratiform Veins (±Am)

In the deposits studied stratiform veins are the main gold-bearing veins. Typically they are ribbon veins comprising alternating layers of laminated quartz and host rock slate, conformable to bedding

Table 1. Relation of quartz vein polytypes to regional deformation.

Country Rocks		Veins			
*Deformation Event	*Structure	Relative Age	Polytype	**Gangue Minerals	**Ore Minerals
Late	Faults and joints Local cleavage Kink bands		as joint infillings other veins	qz, kf, ch, sr, ca, qz	as, cp, ga, py, po, sp, ?Au
GRANITOID PLUTONISM (Assumption: that the granitoids are approximately the same age as the Sherbrooke pluton = 369 ± 3 Ma Rb/Sr whole rock isochron)					
STATIC METAMORPHISM					
D_C (?Acadian)	Crenulation cleavage Intersection lineation Minor folds and crenulations	Syn- or pre-D_C	Quartz tension gashes in earlier carbonate-rich stratiform veins	qz	
D_G (?Acadian)	Slaty cleavage Multistage pressure solution cleavage Intersection, shape and mineral lineation Major (and minor) folds	Late Syn-D_G	Vertical veins Radial veins in fold hinge	qz, ca, ch (kf) qz	
		Syn-to pre-D_G	Concordant lenses in fold hinge Discordant veins in fold limbs	qz qz, incl, ch	as
D_S (?Acadian)	Cleavage Quartz rodding lineation Mesoscopic folds	Pre-or Syn-D_S	Step and side veins Stratabound and side veins Stratiform and side veins	qz, kf, mu, ch, incl, ca, sr qz, incl, ch, ca, sr qz, incl, ch, sr, ca, gr	as, py, po Au as, py, po, ga, sp, Au as, py, po, ga, sp, Au

* Deformation events and structural fabric elements are named after type localities and abbreviated as follows:
D_C - Country Harbour; D_G - Guysborough; D_S - Sherbrooke

Bold abbreviation indicates essential constituent
Bold type in vein polytype indicates crosscutting relationship

**Abbreviations:

as:	arsenopyrite	ch:	chlorite	incl:	inclusions	py:	pyrite
Au:	gold	cp:	chalcopyrite	Kf:	K-feldspar	sp:	sphalerite
bi:	biotite	ga:	galena	mu:	muscovite	sr:	sericite
ca:	carbonate	gr:	graphite	po:	pyrrhotite	sx:	specularite
						to:	tourmaline

(Fig. 7). They appear to be restricted to slate horizons. At, or near, fold hinges they are deformed by both F_g upright (Fig. 8), and F_s recumbent (Fig. 9), minor folds. At Isaacs Harbour, L_s quartz rodding on gold-bearing lamination planes is common (Fig. 10). The quartz rods are folded where the veins are corrugated by F_g (Fig. 11). On fold hinges, the L_s quartz rodding is oriented about 45° to the axial plane of F_g folds (Fig. 12). For discussion of these structures see Keppie (this volume). Honeycomb texture is often present in stratiform veins, and at Isaacs Harbour is associated with L_s quartz rodding (Fig. 12). Carbonate and chlorite are common gangue constituents (Fig. 13). Arsenopyrite is commonly the most abundant sulphide, in places comprising up to about 80 per cent of the vein (Fig. 14), but in some deposits (e.g. Burke lead, Isaacs Harbour) it is rare. Auriferous stratiform veins are characterised by the presence of minor quantities of metallic minerals visible in hand specimen. These include pyrite, pyrrhotite, galena, sphalerite, chalcopyrite and specularite. At the Beaverdam Mine (outside the study area, northwest of Sheet Harbour, Halifax County), laminated stratiform veins display spectacular columnar structures (Fig. 15). Inspection of these in thin section, reveals that the laminations are due to partings of sericite and graphite while the dark columnar structures also contain fine grained chlorite (confirmed by X-ray diffraction, J. Henderson, personal communication, 1982). In the stratiform veins of the study area, laminations and columnar structures are only locally preserved in small, unstrained, regions of the vein, particularly on the straighter limbs of larger folds, but have been obliterated by recrystallization of quartz in the F_s and F_g fold hinges. This indicates that these internal structures were formed prior to D_s. Interestingly these laminations and columnar structures are similar to descriptions (Walter, 1976) of structures observed in the apron of siliceous sinters around modern geyers (Fig. 16).

Stratabound Veins (> Au)

Typically, these are boudinaged quartz veins often with irregular, chloritized, inclusions of slate (Fig. 17). They are restricted to specific horizons, but may locally crosscut bedding. They are present in psammites, semipelites and slates. Thin varieties display only weak pinch and swell structures (Fig. 18). Within most veins the intermediate axes of the boudins are aligned vertically (Fig. 17) and long axes horizontally (Fig. 19), but the degree of necking is often greater in those boudins aligned parallel to the axes of F_g folds (long axes horizontal, Fig. 19). S_g cleavage has been deformed during boudinage (Figs. 17 and 19) indicating that the major period of extension occurred during late F_g or post-F_g folding. At Wine Harbour, bilateral arsenopyrite + sericite wall rock alteration (with minor tourmaline) affects the host rocks up to 20 cm from the walls of stratabound veins (Fig. 20). This alteration is often characterized by the development of large, arsenopyrite pseudo-porpyroblasts with quartz pressure shadows (Figs. 20 and 21). Generally, gold is only locally abundant in stratabound veins but, where observed, it is associated with minor metallic minerals similar to those encountered in the stratiform veins.

Step Veins (>Au)

These are discordant veins cutting psammites at high angles and slates at low angles, in a series of folded steps traversing bedding (Fig.

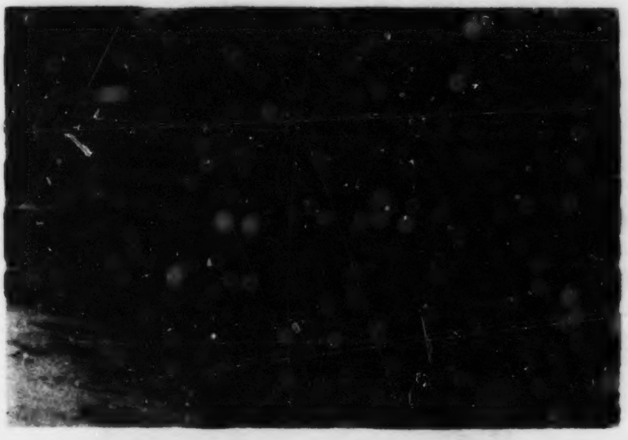


Figure 7. Stratiform vein, 8 cm wide, with alternating layers of slate and quartz, Wine Harbour.

Figure 8. Corrugated auriferous stratiform vein, Mount Uniacke (from Rickard, 1912). Note alternating layers of slate and laminated quartz.

Figure 9. Thin stratiform veins displaying both recumbent F_4 and upright F_5 corrugations, southern limb of North Anticline, Isaacs Harbour. Note vertical side veins cutting and molding with stratiform veins.

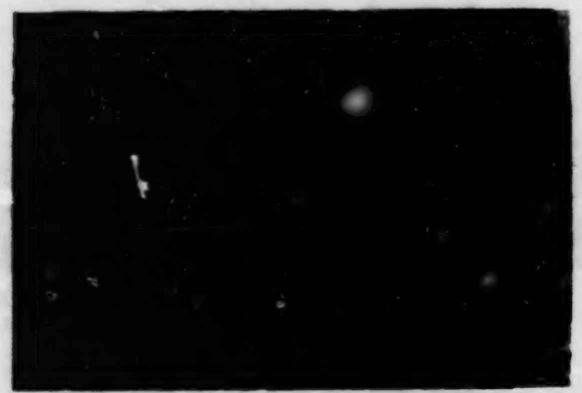


Figure 10. L_5 quartz rodding in stratiform vein. Free gold (white in circled area) occurs along lamination planes, Hurricane Mine, Isaacs Harbour.

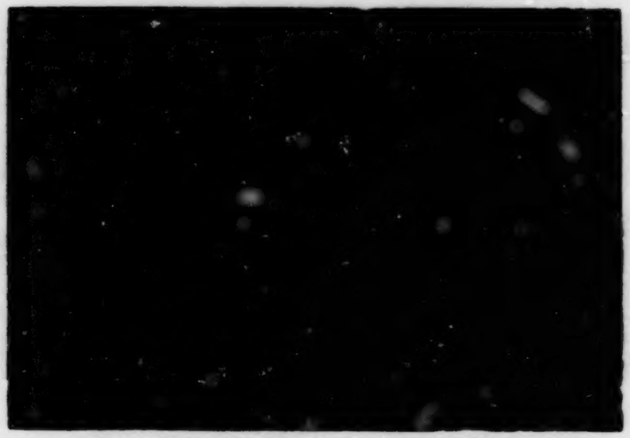


Figure 11. L_8 quartz rods, at 45° to S_9 axial planar slaty cleavage (right to left), folded by F_9 corrugations, stratiform vein, North Anticline, Burke lead, Isaacs Harbour.

Figure 12. Stratiform vein at fold hinge of North Anticline, Burke lead, Isaacs Harbour. Note honeycomb texture (right) and L_8 quartz rodding at 45° to F_9 axial plane (left).

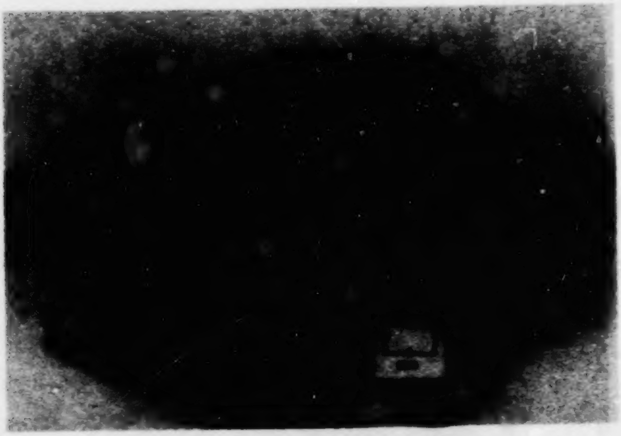


Figure 13. Folded auriferous quartz (grey)-carbonate (white)-chlorite (dark) stratiform vein, Burke lead, Isaacs Harbour.

Figure 14. Arsenopyrite-rich (grey) stratiform vein in thin slate unit. Abundant arsenopyrite (grey spots) in overlying psammite, Wine Harbour.

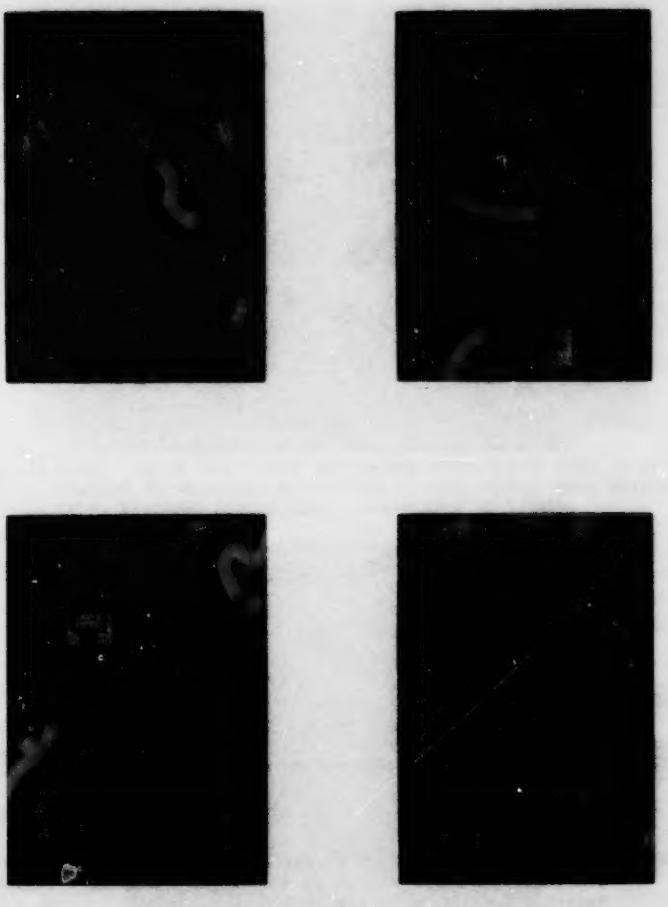


Figure 15. Columnar structures in laminated stratiform quartz veins, Beaverdam deposit, Halifax County.

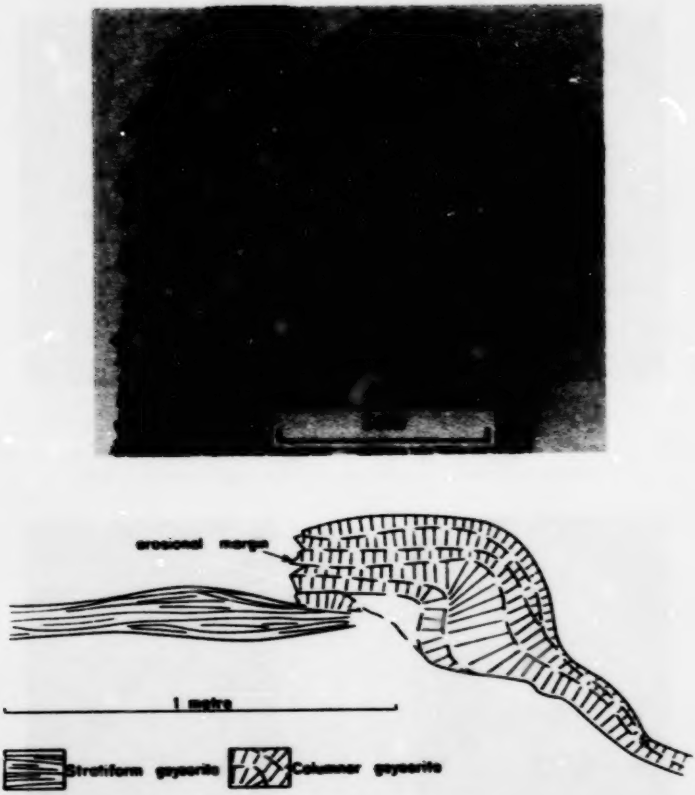

erosional margin
1 metre
Stratiform geyserite
Columnar geyserite

Figure 16. Thin section of columnar geyserite (top) and sketch of a natural erosional section through Mortar Geyser (bottom), Yellowstone National Park (from Walter, 1976).

Figure 17. Plan view of boudinaged auriferous stratabound vein in psammite bounded by sericitic alteration of wall rocks. Note deformation of S_3 cleavage around intermediate zones of boudins.

Figure 18. Thin stratabound vein crosscutting slate horizon, Wine Harbour. Crosscutting folded vertical vein in foreground.

Figure 19. Vertical section of boudinaged stratabound vein in slate, Mount Uniacke. Note deformation of S_1 slaty cleavage.

Figure 20. Arsenopyrite alteration of slate and psammite. Stratabound vein, Wine Harbour.

22). Within psammites, they comprise essentially massive quartz displaying little evidence of boudinage. However, within slates, long axes of step vein boudins are aligned horizontal, parallel to F_g fold axes and intermediate axes are vertical (Fig. 23). Step veins in slates contain aggregates of coarse K-feldspar and/or muscovite, which distinguish them from stratabound veins and inclusions of slate (often sulphide bearing). At Wine Harbour, bilateral arsenopyrite + sericite alteration is well developed up to 50 cm from the vein walls (Fig. 24). Although step veins generally cut stratiform and stratabound veins, one step vein, at Isaacs Harbour, melds with a stratiform vein (Fig. 23). Near the junction with the stratiform vein the K-feldspar bearing step vein becomes bulbous and enriched in pink carbonate. At the junction the bulbous step vein contains inclusions of both slate and stratiform vein material and changes downdip, laterally eastward, into a laminated, white carbonate-bearing, auriferous stratiform quartz-vein (Fig. 23). In places, patches of this stratiform vein form a discontinuous stratigraphic cap to the step vein. Westward, the step vein thins and pinches out both updip and along strike of the strata. No evidence for faulting at this pinch-out was observed. At Isaacs Harbour and Wine Harbour, step veins are cut by S_g pressure solution cleavage, seen as fracture cleavage in thin sections of the step veins. At Isaacs Harbour, both the quartz veins and S_g slaty cleavage have been folded about minor F_c recumbent folds and deformed by flat-lying, axial-planar, S_c crenulation cleavage (Fig. 23). In the step veins, S_c is apparent in outcrop as a fracture cleavage fan parallel to the axial planes of F_c minor folds (Fig. 23). Horizontal alignment and necking of the long axes of boudins in those step veins crosscutting slates, and their relative difference in thickness compared to those in psammites, indicates that considerable vertical extension occurred within the slates. As S_g is deformed about these boudins and crenulated by S_c, this vertical extension in the slates probably occurred between the developments of S_g and S_c. Also the step veins exhibit pinch and swell with vertical alignment of the intermediate axes of the boudins. This suggests horizontal extension parallel to F_g fold axes. Sand volcanoes, common in the psammites at Isaacs Harbour, are also elongated east-west parallel to F_g fold axes (Keppie, this volume). Although no visible gold was observed in the step veins, analyses of the step veins from the Bakers House section demonstrate that they can contain up to 400 ppb Au.

Side Veins (±Au)

These are tightly-folded veins tapering away from T-junctions with stratiform, stratabound and step veins (Fig. 25). Normally they are only present on the stratigraphically lower wall of stratiform veins. They display similar mineralogy and wall rock alteration effects to their "parent" vein. In some side veins, quartz fibres are normal to vein walls around F_g minor folds (Fig. 26). Side veins exhibit a wide variation in attitude to bedding, and their parent veins, but are normally cut by S_g cleavages and often folded by F_g minor folds. Gold is often enriched in the parent vein where side veins join auriferous stratiform and stratabound veins. Side veins cannot be readily distinguished from small step veins because they may contain K-feldspar ± muscovite (e.g. Beaverdam, Halifax County). Both side and step veins represent varieties of the crosscutting "angulars" described by previous workers (e.g. Faribault, 1899; Rickard, 1912; Malcolm, 1929).

Figure 21. Close-up of arsenopyrite pseudo-porphyroblasts, with quartz pressure shadows in psammite; stratabound vein wallrock alteration.

Figure 22. Step veins, Isaacs Harbour. Flat lying in psammites, vertical in slates. Bedding dips 75° to right. Same view as left side Figure 23.

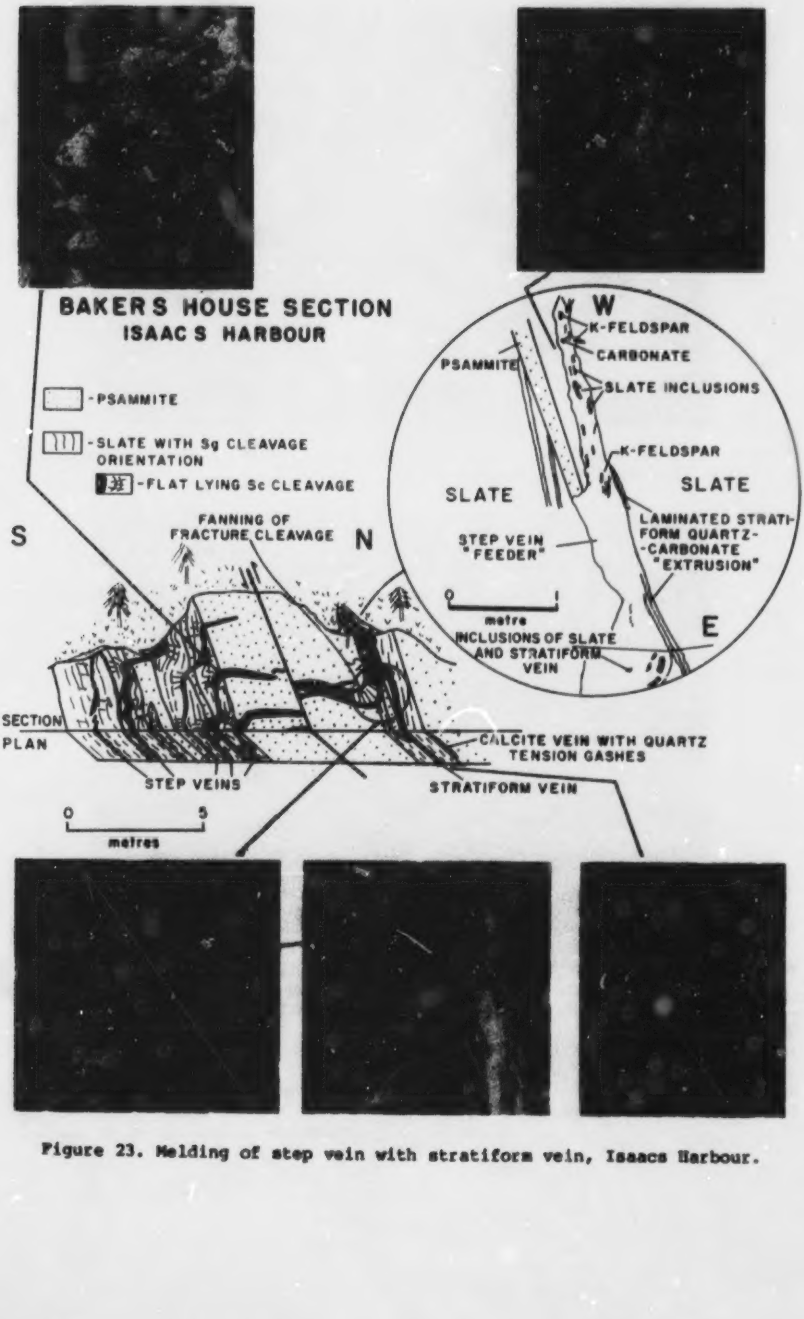

BAKERS HOUSE SECTION
ISAACS HARBOUR
- PSAMMITE
- SLATE WITH Sg CLEAVAGE ORIENTATION
- FLAT LYING Sc CLEAVAGE
S
FANNING OF FRACTURE CLEAVAGE
N
SECTION
PLAN
STEP VEINS
CALCITE VEIN WITH QUARTZ TENSION GASHES
STRATIFORM VEIN
0
5
metres
W
K-FELDSPAR
CARBONATE
PSAMMITE
SLATE INCLUSIONS
K-FELDSPAR
SLATE
SLATE
LAMINATED STRATIFORM QUARTZ-CARBONATE "EXTRUSION"
STEP VEIN "FEEDER"
0
1
metre
INCLUSIONS OF SLATE AND STRATIFORM VEIN
E

Figure 23. Melding of step vein with stratiform vein, Isaacs Harbour.

Figure 24. Step vein with arsenopyrite halo (black spots) crosscutting bedding, Wine Harbour.

Figure 25. Large sulphide-bearing side vein, displaying F_g minor folds, Burke lead, Isaacs Harbour. Main auriferous vein was in mined-out area at right.

Figure 26. Side vein folded within thin slate bed, Wine Harbour. Note quartz fibres normal to vein walls around fold.

Discordant Veins (No Au)

Discordant veins are crosscutting, F_g folded 'tension' gashes in psammites (Fig. 27) or slates (Fig. 28). Varieties in slates are boudinaged (long axes of boudins horizontal) and contain slate inclusions. They are distinguished from step veins by the absence of K-feldspar and/or muscovite and from stratabound veins by the presence of tapering "horns" into psammite, at slate/psammite contacts (Fig. 28). Both varieties are cut by S_g pressure solution cleavages.

Concordant Lenses (No Au)

Concordant lenses are small quartz lenses, conformable to bedded psammites, folded around major F_g fold hinges (Fig. 29). Their relation to S_g cleavage is presently unknown, but they may represent quartz infillings during F_g fold dilatency.

Radial Veins (No Au)

Radial veins are tension veins, in the outer arc of psammite beds, radiating normal to bedding, around tight F_g fold hinges (Fig. 30). They are only weakly deformed by S_g pressure solution cleavage.

Vertical Veins (No Au)

Vertical veins comprise a variety of different mineralogical types (quartz ± chlorite ± carbonate) that cut all the polytypes already described, except the concordant lenses. All are cut and crenulated by S_g cleavages (Figs. 31, 32 and 33). They appear to be deformed infillings of ac-joints attendant to F_g folds.

Figure 27. F_g folded discordant lens in psammite, Wine Harbour.

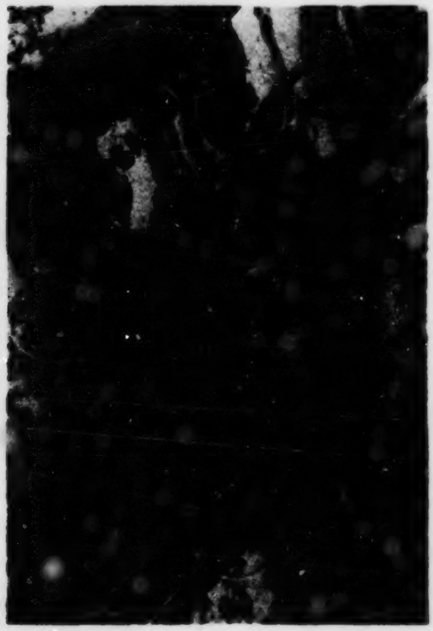


Figure 28. F_g folded discordant lens in slate, Indian Harbour. Note pinched-out "hooks" where vein enters psammite (circled).

Figure 29. Concordant quartz lens in psammite (arrow), Burke lead, Isaacs Harbour.

Figure 30. Radial veins in psammite, anticlinal hinge, Burke lead, Isaacs Harbour.

Figure 31. Folded vertical veins cutting stratiform veins, Wine Harbour.

Figure 32. Folded vertical vein cutting stratabound vein, Wine Harbour.

Quartz Tension Gashes (No Au)

Quartz tension gashes are quartz infillings of ac-tension gashes within carbonate-rich stratiform veins (Fig. 34). They may be related to either D_g or D_c horizontal extension (see Keppie, this volume).

Late Quartz Veins (No Au)

Late quartz veins comprise quartz infillings of late joints of various orientations, and relative ages, that warp S_g cleavages (Fig. 35).

ac-Joint Infillings (±Au?)

Ac-joint infillings are northerly-trending quartz-±-feldspar-sericite-chlorite-arsenopyrite-specularite veins cutting and warping S_g cleavages. Intense bleaching, accompanying sericitic wall rock alteration, within 10 cm of the vein walls is common (Fig. 36). Many veins display "horns" of quartz asymmetrically restricted to one side of the main vein (Fig. 37). One of these at Crook Cove, Seal Harbour, (Fig. 38) is sulphide-rich and might be auriferous because gold has been reported from the beach at this locality (Mossman, 1982). Many of these veins contain galena, sphalerite and a variety of other sulphides. Both the late quartz veins and the ac-joint infillings may represent activation of regional fault systems during the Hercynian or later (see Keppie, this volume).

DISCUSSION

In the study area, individual gold deposits comprise a stratigraphically-stacked series of thin (less than 25 cm) stratiform and stratabound, auriferous and barren, quartz veins, preferentially located in the slate horizons of the turbidite successions. Commonly they are associated with a variety of crosscutting quartz veins. The deposits tend to be situated at the hinge or on the limbs of, asymmetric monoclinal F_g folds, rather than the essentially upright concentric F_g folds of the Meguma Terrane. They are present on anticlinal hinges as saddle reefs (Goldenville, Upper Seal Harbour, North Star-Burke-Hurricane Point), or on steep fold limbs (Wine Harbour, Lower Seal Harbour, Mulgrave, Victoria-Goldfinch). At the North Star-Burke deposit, Isaacs Harbour, a stratiform vein (Turn lead) on the steeper southern limb of the North Anticline pinches out at the fold hinge; yet true saddle reefs are present in both underlying and overlying strata.

Saddle reefs offer greater potential for ore because stratiform, stratabound and side veins have been corrugated by F_s and F_g minor folds (the "barrel" veins of earlier literature). The best tonnages were obtained from "crumple" zones (Malcolm, 1929; Rickard, 1912). Here, intense buckling, caused by superposition of tight upright F_g folds on tight recumbent F_s folds has doubled or tripled the volume of quartz vein material by fold repetition and remobilization. However, the width of the actual vein does not appear to have increased significantly. The fact that these veins are folded by F_s and F_g, and that gold in many districts was mobilized along S_g cleavages indicates that both the gold and the quartz must have been emplaced prior to the development of F_s, F_g and S_g.

Figure 33. Chlorite-quartz vertical vein deformed by S_3 slaty cleavage, Wine Harbour.

Figure 34. Quartz tension gashes (grey) in carbonate-rich stratiform vein, Isaacs Harbour.

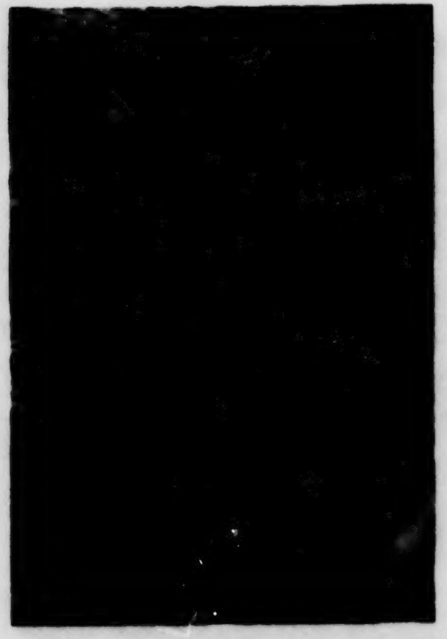


Figure 35. Late quartz vein cutting strike of both bedding and D_g pressure solution cleavage at about 45°, Ragged Point, Isaacs Harbour.

Figure 36. Bleached alteration (sericite + arsenopyrite) around quartz + K-feldspar + chlorite ac-joint infilling, Ragged Point, Isaacs Harbour.

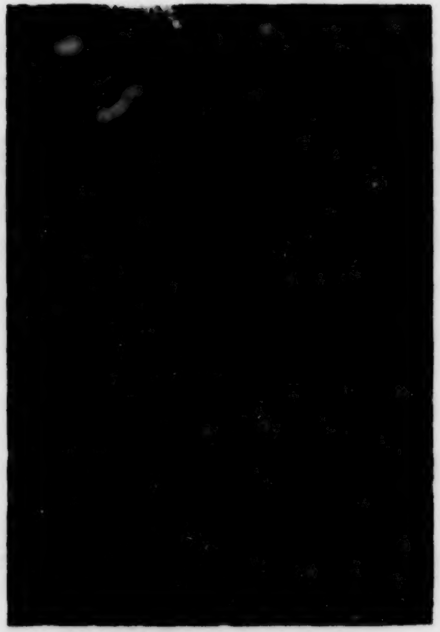


Figure 37. Same vein as Figure 36. Note asymmetric horns, and slight distortion of S_q pressure solution cleavage in psammite.

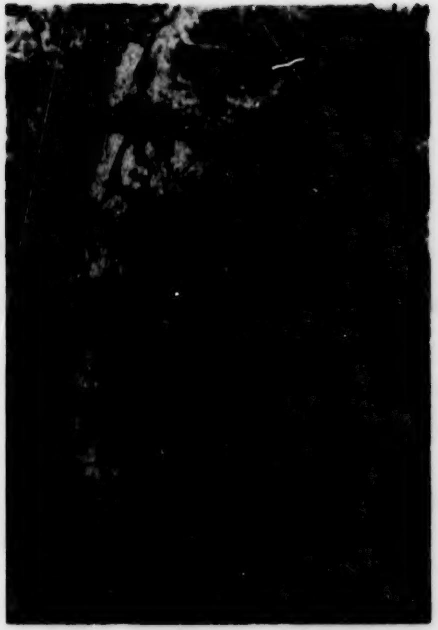


Figure 38. Sulphide-rich ac-joint infilling with assymmetric "horns", Crook Cove, Seal Harbour.

The importance of limb veins was noted by Goodwin (1935) who, in his description of the Lower Seal Harbour mine, noted that the ore zones comprise belts of slate, up to 20 m wide, in which, "the slate and quartz are intermingled in irregular fashion, a brecciated structure being distinctly visible in places" (Fig. 39).

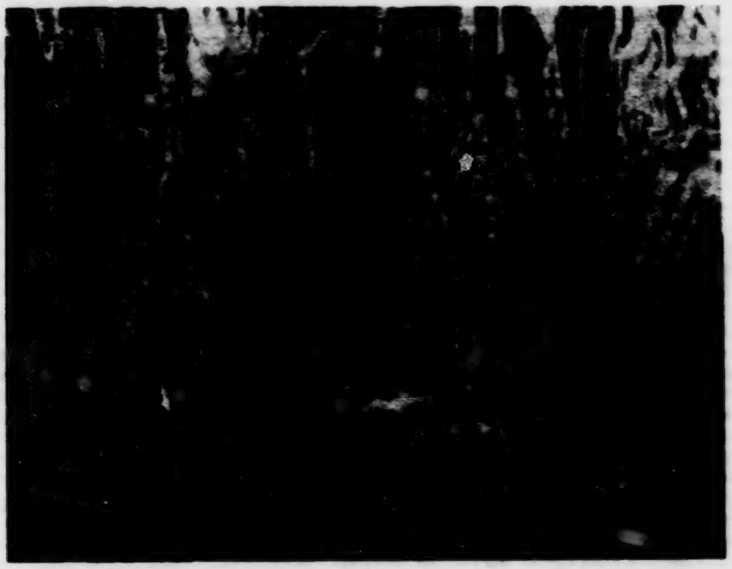


Figure 39. Typical ore, Lower Seal Harbour. Note shadow of miner at right (from Goodwin, 1935).

Most of the gold in the deposits of southern Guysborough County is contained in stratiform ribbon veins. These veins are distinguished from all the other quartz vein polytypes by their characteristic laminations in quartz, and ribbon-like intercalations of quartz with carbonate and slate. As early as 1870 Hind (*in* Rickard, 1912 p. 36-37) distinguished "laminated veins" (stratiform veins), which he considered to be sedimentary, from later "intercalated veins" of massive quartz in the form of en echelon discs (boudinaged stratabound veins). He noted that both types could occur in psammites but were more prevalent in slates. Where veins occurred in slate, "the slate itself is found to be auriferous, and the whole mass is frequently worth crushing". Later literature appears to have ignored Hind's observations and in regard to auriferous slate, Malcolm (1929) dismissed it as gold associated with thin quartz veins. However, it may interest the reader that Earl Malloy of Goldboro, has known about auriferous slate since 1906 (when he worked the Goldboro camp as a boy), and now, with his partner Dale Henderson, prefers this material for his custom mill, "as its cosier to crush than quartz" (personal communication, 1982). The author observed several pieces of auriferous slate at their mill and collected samples of this material from the Victoria Mine dump.

The true dimensions of the stratiform and stratabound veins are obscured by folding and lack of subsurface information, but they appear to be preferentially elongated in the general direction of the Acadian fold axes, being up to a thousand metres along strike and a few hundred metres along dip.

A direct genetic link between the granites (Rickard, 1912; Newhouse, 1936) and the auriferous veins of southern Guysborough County is precluded because the granites are post-D_c (Smith, 1981) and the veins are pre-D_g. However, in northern Guysborough County (amphibolite facies) granitoid dykes have mobilized gold (Smith, this volume).

Models involving dilatency during F_g folding (Faribault, 1899; Boyle, 1979) can be applied to several of the later, barren, quartz veins, but do not readily explain F_s and F_g minor folding of the auriferous stratiform veins. Keppie (1976; this volume) has noted that saddle reef districts are characterized by F_g cone folding. Although cone folds, may be a useful guide for the location of saddle reefs, there is little evidence for introduction of new gold during cone folding.

Graves and Zentilli (1982) presented an elegant model for the auriferous stratiform veins based on prefolding hydraulic fracturing of slates by overpressured pore fluids during fast tectonic loading and greenschist facies metamorphism. Their model assumes that horizontal tension fractures developed in response to horizontal tectonic stress and that auriferous veins are located in slates because their low permeability would allow build-up of fluid overpressure. Their model does not easily account for auriferous veins in psammites or how a K-feldspar + muscovite cross-cutting step vein can meld into a stratigraphically overlying carbonate-bearing laminated stratiform vein. Although horizontal tensile failure as advocated by Graves and Zentilli (1982) is theoretically possible, it requires the special condition that the minimum effective stress be vertical and the maximum effective stress horizontal (Secor, 1965). Other orientations of the principal stress axes will yield vertical tension fractures (Secor, 1965). Thus, normal loading of a sedimentary basin (maximum effective stress vertical) will result in obliquely or vertically oriented tension fractures. In this regard, Magara (1981) demonstrated that fluid movement in the shale sequences of sedimentary basins is by both upward and downward intergranular flow or by flow through vertical fractures. Graves and Zentilli (1982) proposed that the horizontal stress was tectonic. However, studies by Watts (1983) on the North Sea oilfield, where halokinetic doming is evident, have demonstrated that the earliest fractures (prepressure solution, as required by the Graves and Zentilli, 1982, model) are in fact oblique shear fractures. Tension fractures are present, but are vertical and later than pressure solution. From considerations of deep burial and prograde metamorphism of thick sedimentary sequences, Norris and Henley (1976) have shown that thermally induced fractures lead to the formation of early large hydraulic fractures and vein systems that crosscut the metamorphic fabric.

In addition, none of the above models explains the presence of discrete disseminations of native gold in slate.

Sedimentary theories of origin (Hunt and Hind *in* Rickard, 1912) account for gold in the slates and stratiform veins, but fail to explain the stratabound, side and step veins, or their wall rock alteration.

Preliminary fluid inclusion studies on vein quartz by M. Sommer (personal communications, 1983) indicate that pseudo-secondary inclusions have separate liquid and carbon dioxide vapour phases that yield filling temperatures of about 270°C and salinities of 7 weight per cent NaCl. This is in general agreement with the work of Graves and Zentilli (1982).

Microprobe analyses of native golds (electrum) indicate they contain less than 10 atomic per cent Ag. From the elctrum-tarnish curves of Barton and Toulmin (1964) this would correspond to sulphide fugacities well above the stability field of arsenopyrite determined by Kretschmar and Scott (1976). However, because no argentite was observed in the samples analyzed, the true sulphur fugacity could not be determined. Microprobe analyses of arsenopyrites reveal considerable elemental zonation in many grains and wide compositional variation between grains within any deposit. Many of the deposits of southern Guysborough County comprise sulphur-rich (arsenopyrite + pyrrhotite ± pyrite) assemblages rather than arsenic-rich (arsenopyrite + loellingite) assemblages. Mutual grain boundaries are comparatively minor and there is little evidence that the iron sulphides were in equilibrium with arsenopyrite. Arsenopyrite compositions are less than 35 atomic per cent As with most values about 32 to 33 atomic per cent As. Without an independent measure of sulphur fugacity, these arsenopyrite compositions only yield an estimate of the upper temperature limit when applied to Kretschmar and Scott's (1976) geothermometer. For southern Guysborough County this maximum is 550°C, but the actual formation temperature was probably much lower.

Although he chose to ignore his own philosophy, Rickard (1912) propounded the only reasonable solution to the origin of the gold and the veins. "The ore found by man represents a long series of solutions and precipitations, diffusions and concentrations, brought about by chemical and physical conditions that varied frequently during that long time in which nature has been at work" (Richard, 1912, p. 49).

In order to explain the variety of veins, with different times of formation, the author prefers a polygenetic model for their origin.

POLYGENETIC MODEL FOR GOLD AND QUARTZ VEINS

Although geochemical and isotopic data are required to confirm the model it is tentatively proposed that the following sequence of events controlled the deposition of gold and the quartz veins.

Stage 1. Submarine Hydrothermal Venting and Sedimentation

The association of stratiform, stratabound and step veins (Fig. 23) can be explained by the submarine hydrothermal-vent hot spring model shown in Figure 40. Hot hydrothermal solutions, ascending fractures, altered the adjacent wall rocks and precipitated K-feldspar + muscovite + quartz assemblages (step veins). As the hydrothermal solutions reached the ocean floor they built up an apron of siliceous sinter (geyserite) around the discharging vent, similar to modern subaerial geysers. Such geysers at Broadlands, New Zealand, are known to be able to precipitate ore grade

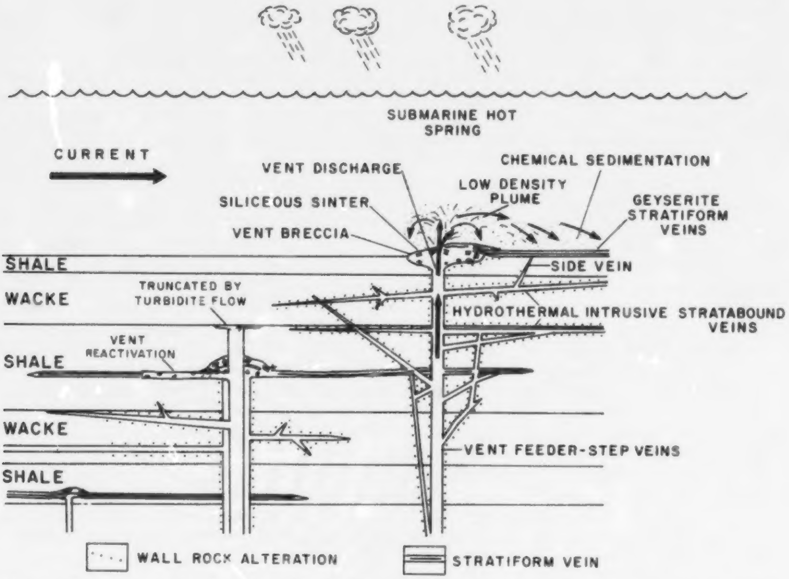

SUBMARINE HOT SPRING
CURRENT
VENT DISCHARGE
CHEMICAL SEDIMENTATION
LOW DENSITY PLUME
SILICEOUS SINTER
GEYSERITE STRATIFORM VEINS
VENT BRECCIA
SHALE
SIDE VEIN
WACKE
TRUNCATED BY TURBIDITE FLOW
HYDROTHERMAL INTRUSIVE STRATABOUND VEINS
VENT REACTIVATION
SHALE
WACKE
VENT FEEDER-STEP VEINS
SHALE
WALL ROCK ALTERATION
STRATIFORM VEIN

Figure 40. Submarine hydrothermal vent model of gold-quartz vein formation.

quantities of gold and silver (Weissberg, 1969). On eruption into the marine environment, the hydrothermal solutions would have undergone a rapid change from relatively high temperature and low pH, conditions in the vent to the low temperature, higher pH and probably lower Eh, conditions present on the ocean bottom. Such physico-chemical changes would have favoured the direct precipitation of gold, sulphides, carbonates and quartz; probably as colloidal precipitates forming a "white smoker" similar to the more metal rich "black smokers" documented from the floor of the Pacific Ocean (Spiess et al., 1980). If the salinity of the fluid inclusions (about 7 weight per cent) is representative of either effluent from the submarine vent, or effluent mixed with, and diluted by, seawater, it would suggest that the hydrothermal solutions vented into seawater as low density plumes (Turner and Gustafson, 1978) with nonlinear density behaviour similar to Sato's (1972) Type 3 or Type 2 mixing curves. Type 3 forms a buoyant plume whereas Type 2 forms a buoyant plume that eventually falls back on itself as it becomes heavier by cooling. Turner and Gustafson (1978) have pointed out that this falling back could lead to oscillations of the outflow from the vent and layering of precipitates from the plume. If the period of these oscillations were short this mechanism could account for the laminations in the quartz of the stratiform veins. Marine currents would have moved Type 3 buoyant plumes sideways, thus increasing the distance from the vent over which precipitation could occur. Precipitation from the plume may have been as a rain of particles or as a colloidal suspension that increased the net density of the plume, causing it to fall to the ocean floor. The phyllosilicate-rich laminations in the quartz of the stratiform veins may represent sedimentation of hydrothermal phyllosilicates from the plume whereas the intercalated layers of slate in the stratiform veins probably represent either pelagic sedimentation or small fine grained turbidity flows during the intermittent periods when the vent became blocked by seals of silica. Below the vent the hydrothermal solutions could have flowed laterally through the sediments, enclosing the feeder, as a fluidized system of hydrothermal sills and dykes (the stratabound and side veins) below the sediment-seawater interface as suggested for Mt. Lyell by Turner and Gustafson (1978). Another possibility is that fracturing of the soft sediments may have been achieved by baking and bilateral alteration of the wall rocks by a gas streaming process. At the vent, the sinter apron would have suffered brecciation during violent eruptive pulses. An example of this is the bulbous mass of quartz, with inclusions of slate and stratiform vein, connecting the step and stratiform veins in Figure 23.

The occurrence of disseminated native gold with abundant arsenopyrite and other sulphides in the slates can be explained by local turbulent flow within a buoyant plume such that colloidal sized particles of gold and other minerals would have been rapidly dispersed to the outer parts of a plume, eventually to settle out with pelagic sediments. Alternatively, turbulent conditions may have been maintained over vent systems, during fine grained, low density, turbidite current deposition. This would have enabled clays to remain in suspension for a longer than normal period, thus allowing them to become enriched with gold and other minerals discharging from the vent.

Gold and sulphide precipitation in both the slates and stratiform veins could have been aided by the reducing action of organisms. Estep (1982) noted that many of the hot springs at Yellowstone are populated by varieties of algae that inhabit environments from acid to alkaline pH. Because intense organic activity has been observed around the black smokers of the Pacific Ocean (Ballard and Grassle, 1979) it is reasonable to suggest similar activity around vents in the Meguma Group and that the unusual columnar structures might be organic in orgin. Much of the gold may have been originally deposited as surface coatings or sulphides in the manner recently suggested by Bancroft and Jean (1982). During diagenesis and/or later metamorphism the colloidal particles and coatings would have crystallized to minerals now seen as the pseudo-porphyroblasts of gold and sulphides.

Ellis (1979) has shown that the stability fields of calcium and potassium minerals in active geothermal systems are a function of temperature, M_{CO2} concentration and the solution ion ratios α_{Ca}/α_{H2} and α_K/α_H. At 260°C, deep geothermal waters with low M_{CO2} near 0.01 coexist with zoisite, wairakite and potassium feldspar (Wairakei, New Zealand) whereas deep waters with high M_{CO2} near 0.15 co-exist with potassium mica, potassium feldspar and calcite (Broadlands, New Zealand). In active geothermal fields, boiling of hydrothermal fluids occurs in the upper 1000 m. This boiling is attended by loss of CO_2 from the waters which results in a consequent rise in water pH. At Broadlands, this first loss of steam causes the water to precipitate calcite (Browne and Ellis, 1970). After appreciable steam and CO_2 loss, Broadlands water composition moves from the phase field of potassium mica to potassium feldspar due to increase in the $a_K{}^+/a_H{}^+$ ratio that accompanies a rise in pH. The step veins of southern Guysborough County have potassium feldspar + carbonate + potassium mica assemblages similar to the deeper parts of Broadlands. Also the fluid inclusion data from quartz in the step veins suggest similar physical conditions to Broadlands: low salinity, filling temperatures of 270°C and the existence of a separate carbon dioxide vapour phase.

Ellis (1979) has shown that lowering of water temperature in the upper parts of geothermal systems causes precipitation of micas or kaolinite because the potassium and sodium mineral stability field boundaries shift toward higher $a_K{}^+/a_H{}^+$ and $a_{Na}{}^+/a_H{}^+$ with decreasing temperature. Thus expulsion of water from the vent (the step veins) into lower temperture near surface conditions as soft sediment sills (stratabound veins) or seawater plumes precipitates (stratiform veins) will shift water compositions from the stability field of potassium feldspar to that of sodium and potassium phyllosilicates. This explains the lack of feldspar in these veins. Expulsion of the CO_2-rich vapour phase, from the vent, into seawater will cause supersaturation of calcite and the precipitation of the intercalated layers of cabonate present in the stratiform veins.

Several geothermal areas of the world occur in sediments with no obvious volcanic activity (e.g. Kizildere, Turkey, and Larderello, Italy), although these are in regions of intense tectonic activity (Ellis, 1979). The precious metal-bearing geothermal wells at Broadlands are hosted by Quaternary volcanic rocks that are underlain by a thick Mesozoic basement of greywacke and argillite (Weissberg et al., 1979). This Mesozoic basement underlies much of the North Island of New Zealand, including the silver-gold veins in the Miocene volcanics of the Coromandel Peninusla. Chemical (Mahon, 1967) and sulphur isotope studies (Giggenbach, in Weissberg et al., 1979) suggest that the Mesozoic basement are possible sources of the elements in the waters at Broadlands, although leaching of the volcanic host rocks and mantle sources are probably important. Similarly, gold and other metals may have been leached from the greywackes and slates of the Goldenville Formation.

Virtually nothing is known about the basement to the Meguma Group or the tectonic controls on the Meguma basin. Keppie (1982a and b) considers the Meguma Terrane to have formed in an intracratonic trough during a transpression stage of tectonism. A model for Early Paleozoic sedimentation and tectonism in the Meguma basin is presented in Figure 41. If auriferous veins result from hot spring activity then the basin must have been subjected to regional faulting during Goldenville sedimentation. Whether the faulting was related to graben or transcurrent tectonics is unknown. Gold veins are rare in the Halifax Formation, so the change from predominantly greywacke to shale from the Goldenville to the Halifax probably marked the cessation of hot spring activity accompanying basinal subsidence.

Stage 2. D_8-D_9 Events

Mesoscopic F_8 folds are rare. One of these which occurs south of the North Star-Burke deposit at the Isaacs Harbour lighthouse, appears

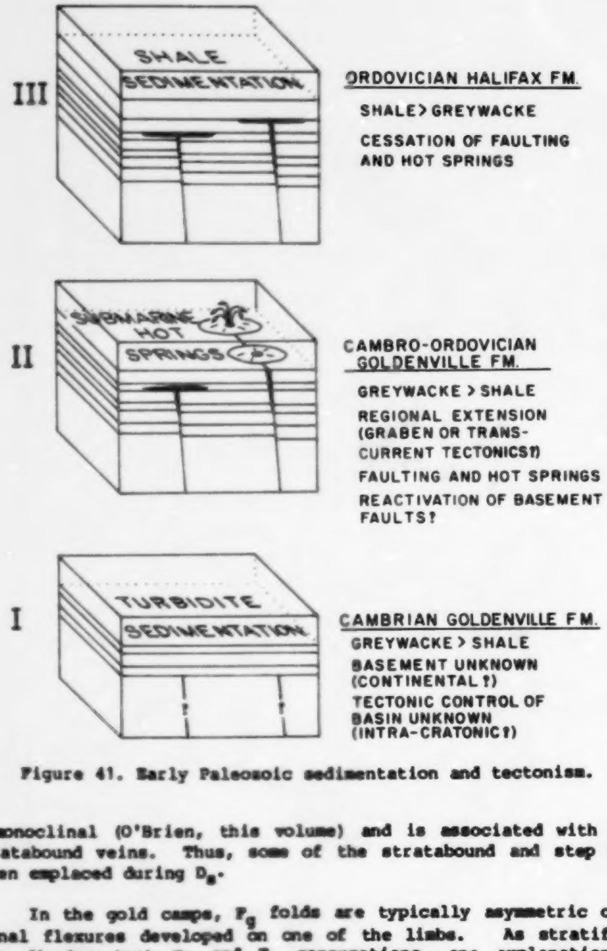
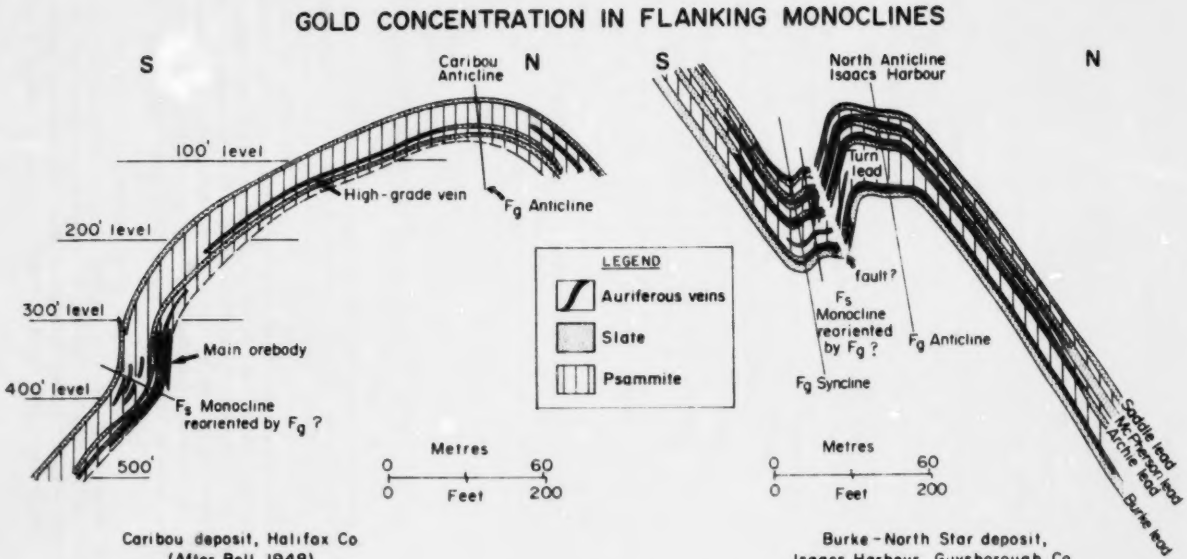

III
SHALE
SEDIMENTATION
ORDOVICIAN HALIFAX FM.
SHALE > GREYWACKE
CESSATION OF FAULTING AND HOT SPRINGS
II
SUBMARINE HOT SPRINGS
CAMBRO-ORDOVICIAN GOLDENVILLE FM.
GREYWACKE > SHALE
REGIONAL EXTENSION (GRABEN OR TRANS-CURRENT TECTONICS?)
FAULTING AND HOT SPRINGS
REACTIVATION OF BASEMENT FAULTS?
I
TURBIDITE
SEDIMENTATION
?
?
CAMBRIAN GOLDENVILLE FM.
GREYWACKE > SHALE
BASEMENT UNKNOWN (CONTINENTAL ?)
TECTONIC CONTROL OF BASIN UNKNOWN (INTRA-CRATONIC ?)

Figure 41. Early Paleozoic sedimentation and tectonism.

to be monoclinal (O'Brien, this volume) and is associated with both step and stratabound veins. Thus, some of the stratabound and step veins may have been emplaced during D_s.

In the gold camps, F_g folds are typically asymmetric often with monoclinal flexures developed on one of the limbs. As stratiform veins commonly display both F_s and F_g corrugations, one explanation for the present shape of the major folds is that F_s monoclines were developed about the faults that acted as feeders for the hot spings, and gold deposits, and then became the focal point for later main Acadian (F_g) folding (Fig. 42).

Initial shortening of the strata during both early F_s and F_g may have resulted in folding of pre-F_s stratiform, stratabound, side and step veins in slates. Flexural-slip folding (Fig. 43) allowed oblique tension gashes to form in the fold limbs. Rapid filling of these with meta-


GOLD CONCENTRATION IN FLANKING MONOCLINES
S
N
Caribou Anticline
100' level
200' level
300' level
400' level
500'
High-grade vein
F_g Anticline
Main orebody
F_s Monocline reoriented by F_g ?
Metres
0
60
0
Feet
200
LEGEND
Auriferous veins
Slate
Psammite
S
N
North Anticline Isaacs Harbour
Turn lead
fault?
F_s Monocline reoriented by F_g ?
F_g Anticline
F_g Syncline
Saddle lead
McPherson lead
Archie lead
Burke lead
Metres
0
60
0
Feet
200

Caribou deposit, Halifax Co
(After Bell, 1948)

Burke - North Star deposit,
Isaacs Harbour, Guysborough Co

Figure 42. Relationship of auriferous quartz veins to F_s monoclines and F_g asymmetric folds.

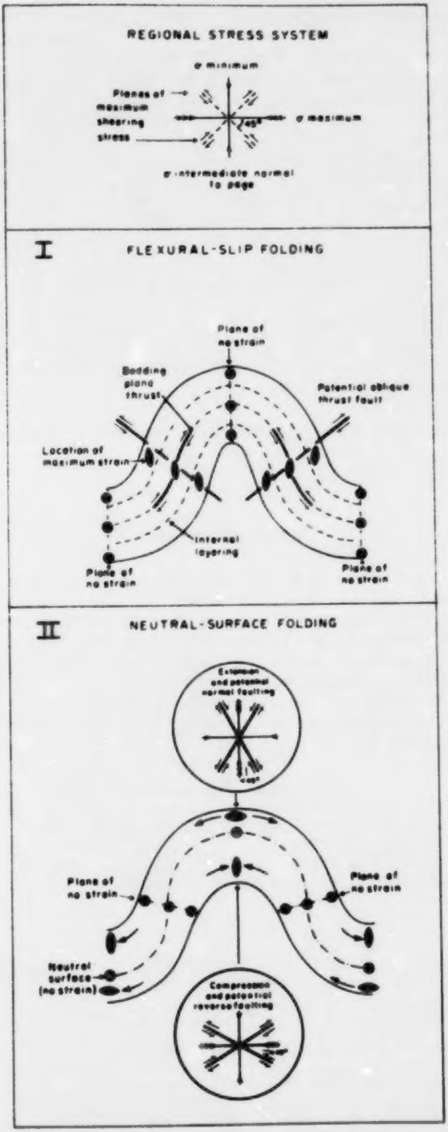

REGIONAL STRESS SYSTEM
σ minimum
Planes of maximum shearing stress
σ maximum
45°
σ intermediate normal to page
I
FLEXURAL-SLIP FOLDING
Plane of no strain
Bedding plane thrust
Potential oblique thrust fault
Location of maximum strain
Internal layering
Plane of no strain
Plane of no strain
II
NEUTRAL-SURFACE FOLDING
Extension and potential normal faulting
45°
Plane of no strain
Plane of no strain
Neutral surface (no strain)
Compression and potential reverse faulting

Figure 43. Parallel folds developed by (I) flexural slip and (II) neutral surface folding (from Colman-Sadd, 1978).

morphogenic solutions enabled quartz to precipitate, forming the disordant veins. Tightening of the F_g folds resulted in preferential extension in the slate beds with rotation and boudinage of discordant veins in slate (Fig. 44). Neutral surface folding (Fig. 43) then resulted in deposition of radial veins in psammites at the fold hinge (Fig. 44). Such extension above a neutral surface at an anticlinal fold hinge may have also caused the pinch-out of the Turn lead stratiform vein (Fig. 42), while compression below the neutral surface would have resulted in further buckling of stratiform, stratabound and side veins and mobilization of gold and soft sulphides along S_g fracture cleavages in veins. Evidence for flexural slip and bedding plane shear is documented by upward rotation of axial planar cleavages (Fig. 6). See also Keppie (1976, and this volume).

Stage 3. Late D_g to Post D_c Events

During late D_g events (Fig. 45), dilatent ac-joints were filled with quartz and folded and cut by S_g cleavages (vertical veins). Subsequently, S_g slaty cleavage was locally deformed with quartz veins during F_c recumbent folding.

The final phase of activity was the emplacement of metalliferous quartz + K-feldspar + chlorite veins along undeformed ac-joints, after static metamorphism (Fig. 45).

ACKNOWLEDGMENTS

Thanks are extended to my colleagues Duncan Keppie, Brian O'Brien, Paul Smith and Amulaya Chatterjee for their assistance and fruitful discussions. John McArthy of Isaacs Harbour offered invaluable help in locating many of the smaller auriferous veins at the Burke lead. Earl Malloy and Dale Henderson showed me the auriferous slates at Goldboro. Particular thanks are extended to Brian Wentzell and Shawn Romkey for field assistance and the staff of the drafting and photographic sections of Nova Scotia Department of Mines and Energy for the illustrations. Kathy Mills is to be commended for her editorial skills.

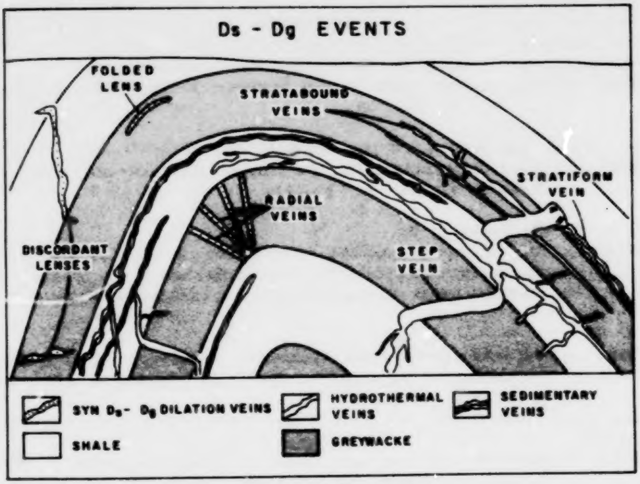

Ds - Dg EVENTS
FOLDED LENS
STRATABOUND VEINS
STRATIFORM VEIN
RADIAL VEINS
DISCORDANT LENSES
STEP VEIN
SYN Ds- Dg DILATION VEINS
HYDROTHERMAL VEINS
SEDIMENTARY VEINS
SHALE
GREYWACKE

Figure 44. D_s-D_g events.

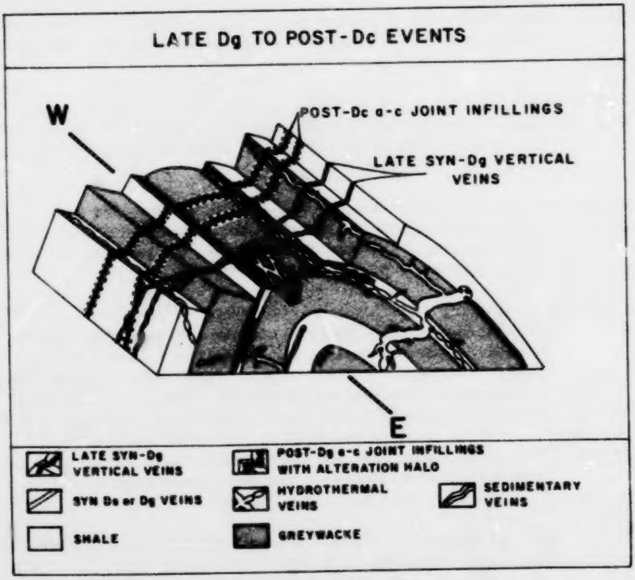

LATE Dg TO POST-Dc EVENTS
W
POST-Dc a-c JOINT INFILLINGS
LATE SYN-Dg VERTICAL VEINS
E
LATE SYN-Dg VERTICAL VEINS
POST-Dg a-c JOINT INFILLINGS WITH ALTERATION HALO
SYN Ds or Dg VEINS
HYDROTHERMAL VEINS
SEDIMENTARY VEINS
SHALE
GREYWACKE

Figure 45. Late D_g to post-D_c events.

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GEOLOGY OF THE COCHRANE HILL GOLD DEPOSIT, GUYSBOROUGH COUNTY, NOVA SCOTIA*

P. K. Smith

ABSTRACT

The Cochrane Hill gold deposit is located within the Cambro-Ordovician Meguma Group of southeastern Nova Scotia. A detailed examination of this turbidite-hosted deposit indicates a polygenetic origin for the vein mineralization. The Meguma Group sediments probably represent the original source for much of the gold in this deposit. Much of the visible gold is found in the wall rock lithologies adjacent to quartz rich veins. At least six different vein types occur at Cochrane Hill (type A to type F). These include, from oldest to youngest, type A stratiform microcrosslaminated veins, type B stratiform/stratabound veins, type C bedding-parallel veins, type D flat angular veins, type E crosscutting pegmatoid veins and type F crosscutting high angle stringers. The relative age range of these veins is from late syn-sedimentation to post-Hercynian Orogeny. The relative ages of veins and gold mineralization is based on crosscutting relationships with (i) the Acadian and overprint structures, (ii) porphyroblastic mineral growth during the Acadian amphibolite grade static metamorphism, and (iii) subsequent Devono-Carboniferous plutonism. Although much of the gold is associated with the earlier veins, remobilization and/or secondary enrichment has occurred not less than four times during the geological history.

Regional, amphibolite grade, static metamorphism is presumed to be an Acadian event. Index porphyroblasts include muscovite, biotite, garnet, staurolite and andalusite. In the area of the mine these porphyroblasts are observed to overgrow poorly preserved Acadian structures. Fabrics which deform and augen the index porphyroblasts are regarded as "overprint". These structures are generally dominant over the northern domain, adjacent to the Minas Geofracture. The early structural history is preserved in strain windows where locally competent units preserve Acadian structures. In less competent metapelites these structures have been destroyed or strongly deformed by the overprint structures.

INTRODUCTION

The open-pit of Northumberland Mines Ltd. at Cochrane Hill was mapped at a scale of 1"=10' and selected detailed sections were mapped at 1"= 5'. Detailed cross-sectional strips were logged and samples of all lithologies, including veins were collected for geochemical analyses. Vein typomorphism was documented including relative ages and types of veins as well as associated ore and silicate mineralogy to aid in understanding the genetic history of this deposit.

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*Contribution to Canada-Nova Scotia Co-operative Mineral Program 1981-84. Project carried by Nova Scotia Department of Mines and Energy and by Geological Survey of Canada.

GENERAL GEOLOGY

Rocks underlying west-central Guysborough County belong to the Cambro-Ordovician Meguma Group and consist of metapsammites and metapelites (Smith, 1981). K/Ar ages of 476 ± 19 Ma and 496 ± 20 Ma (Poole, 1971) may reflect the time of deposition of these sediments. The area is divided into southern and northern domains based on structural and metamorphic characteristics (Fig. 1). The boundary, although approximate, is placed at the southern limit of the overprint structures which deform regional metamorphic porphyroblasts. Strata of the northern domain display both Acadian and overprint structures, but those of the southern domain have been affected only by the Acadian structures. Lithologies in the northern domain are metamorphosed to amphibolite facies so that greywackes and shales of the greenschist facies are described as metapsammites and metapelites respectively. Cochrane Hill, lies within the more complex northern domain (Smith, in preparation). Devonian granitic rocks intruded Meguma Group strata to the south and east of Cochrane Hill (Rb/Sr whole rock isochron, Sherbrooke pluton: 369 ± 2 Ma; Rb/Sr whole rock sample, Bull Ridge pluton: 298 Ma and 347 Ma, Keppie and Smith, 1979). Related pegmatite sheets occur to the west, gabbro/diorite to the north and pegmatoid quartz veins occur throughout. The metapsammites and metapelites at Cochrane Hill form an east-west trending, steeply northward dipping, tightly folded succession with the southern limb of a major fold, the Cochrane Hill Anticline, overturned to the north. Porphyroblastic index minerals include static muscovite, biotite, garnet, staurolite and andalusite. K/Ar age dates on similar biotites from the western part of the Province give ages of 344 Ma and 390 Ma (Keppie and Smith, 1979), suggestive of the Acadian metamorphic event (Taylor and Schiller, 1966). These minerals overprint earlier Acadian structures but are augened by later cleavages of presumed Hercynian age.

The Acadian structures in the southern domain are best described by both O'Brien and Keppie (this volume). The Hercynian structures of the northern domain are described briefly within. Locally within the northern domain, especially around Cochrane Hill, both Acadian and overprint structures can be recognized in any one good exposure. The development of the overprint structures appears to be very heterogeneous.

COCHRANE HILL PIT AREA

The open-pit mine area at Cochrane Hill measuring 70 m long, 28 m wide and 10 m deep (Fig. 2) provides an excellent opportunity to study the three dimensional aspects of this gold deposit. In most of the old gold mining districts in Nova Scotia the underground workings and trenches are now flooded or filled making an evalutation of the geology nearly impossible or difficult at best. Because of the complexities of structures, including subhorizontal crenulation cleavages (O'Brien, this volume), and fold axes, two dimensional surface stripping seldom reveals the necessary information to understand the genetic history and the associated mineralization, that can be gained from an open cut.

Lithology

The relative order of lithological units from north to south across the pit area (Fig. 3) is given below. A stratigraphical succession is not implied. Tectonic thicknesses are indicated.

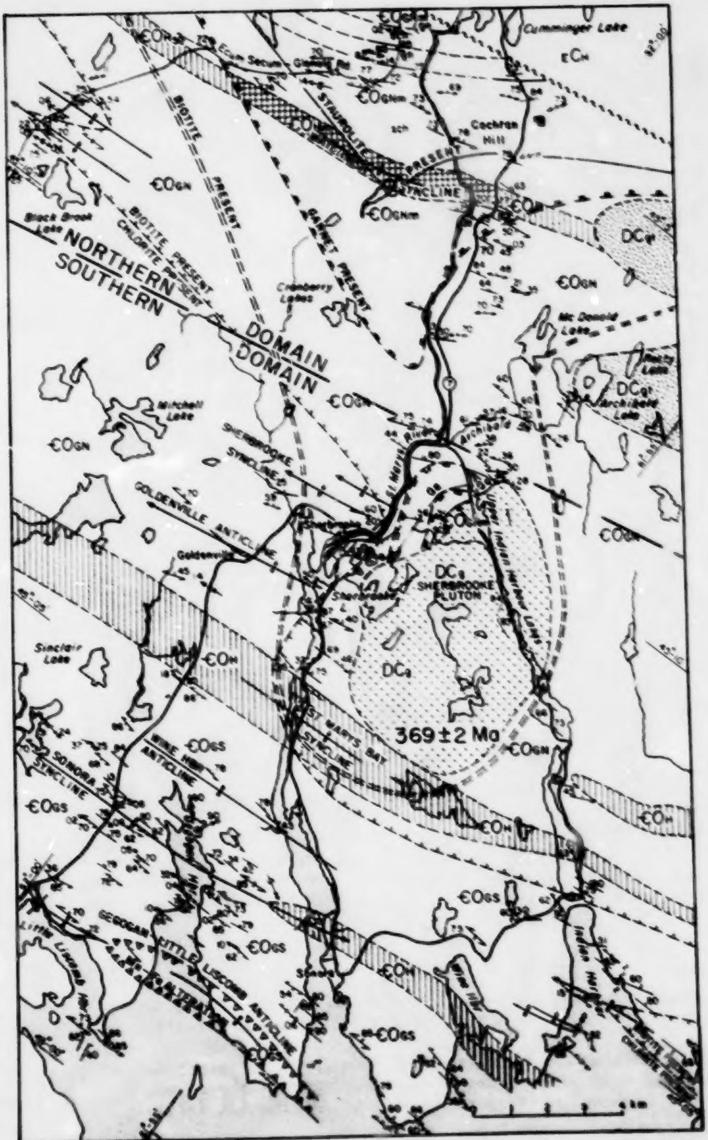

Cumminger Lake
ЄCн
Cochran Hill
STAUROLITE PRESENT
SYNCLINE
ЄOgnm
ЄOgn
BIOTITE PRESENT
GARNET PRESENT
BIOTITE PRESENT
CHLORITE PRESENT
Black Brook Lake
NORTHERN
SOUTHERN
DOMAIN
DOMAIN
Cranberry Lakes
DCgt
McDonald Lake
Archibald Lake
Mitchell Lake
SHERBROOKE SYNCLINE
GOLDENVILLE ANTICLINE
Goldenville
DCg
SHERBROOKE PLUTON
Sherbrooke
Sinclair Lake
ЄOн
369±2 Ma
ST MARYS BAY SYNCLINE
WINE HILL ANTICLINE
SONORA SYNCLINE
ЄOgs
LITTLE LISCOMB ANTICLINE
Sonora
D
km

Figure 1. General geological map showing location of the Cochrane Hill gold deposit and the approximate boundary between the northern and southern domains (from Smith, 1981).

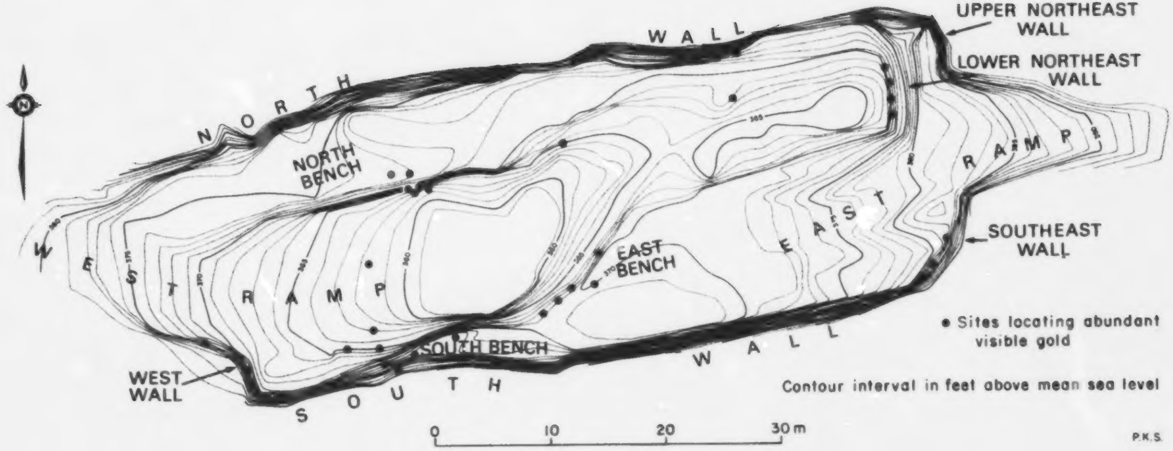

UPPER NORTHEAST WALL
LOWER NORTHEAST WALL
NORTH WALL
NORTH BENCH
WEST RAMP
EAST RAMP
EAST BENCH
SOUTH BENCH
SOUTHEAST WALL
SOUTH WALL
WEST WALL
• Sites locating abundant visible gold
Contour interval in feet above mean sea level
0
10
20
30 m
P.K.S.

Figure 2. Contour map of the topography for the open-pit at Cochrane Hill. Contour intervals are in feet above mean sea level. Appropriate parts of the pit area are designated as "benches, walls, or ramps" to aid in the description. Sites containing abundant visible gold are marked in solid dots. Their distribution is mainly confined to benches and walls where outcrop is well exposed.

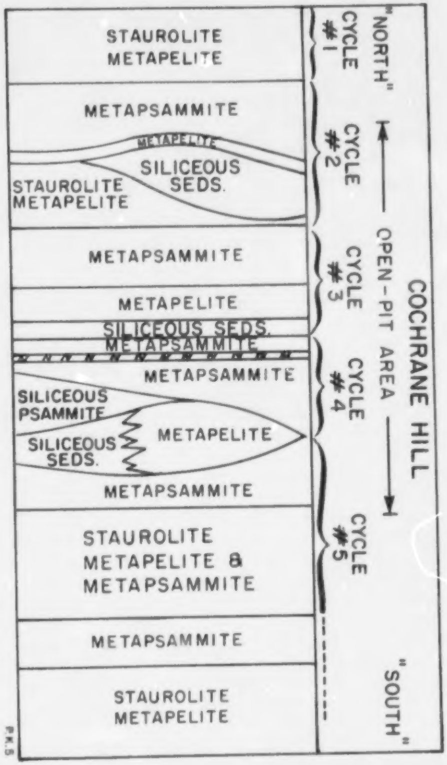

STAUROLITE METAPELITE
METAPSAMMITE
METAPELITE
SILICEOUS SEDS.
STAUROLITE METAPELITE
METAPSAMMITE
METAPELITE
SILICEOUS SEDS.
METAPSAMMITE
METAPSAMMITE
SILICEOUS PSAMMITE
METAPELITE
SILICEOUS SEDS.
METAPSAMMITE
STAUROLITE METAPELITE & METAPSAMMITE
METAPSAMMITE
STAUROLITE METAPELITE
CYCLE #1
CYCLE #2
CYCLE #3
CYCLE #4
CYCLE #5
"NORTH"
OPEN-PIT AREA
"SOUTH"
COCHRANE HILL
P.K.S

Figure 3. Schematic diagram depicting apparent cyclic nature of lithological units across the Cochrane Hill mine area. Locally within individual units (especially schist) tight isoclinal minor folding with subhorizontal fold axis, deform both veins and bedding. A large synform is situated towards the south and the beds apparently young in the same direction.

NORTH TO SOUTH

a) graphite rich metapelite with abundant calc-silicates and finely disseminated sulphides (≈5 m thick).

b) manganese calc-silicate bearing metapsammite with abundant quartz vein development and pseudo-porphyroblastic arsenopyrite mineralization (≈10 m thick) * Au bearing.

c) siliceous metapsammite with calc-silicates and abundant quartz veins (≈5 m thick) * Au bearing.

d) staurolite bearing metapelite with only minor quartz vein development; thin veins crosscut staurolite porphyroblasts (~7 m thick).

e) metapsammite with calc-silicate and interbedded metapelite containing numerous quartz veins and several graphite-rich shear zones parallel to bedding; locally massive sulphide in veins along the northern margin of the unit (~15 m thick) * Au bearing.

f) fragmental brecciation zone bounded by thin soft graphite-rich boundaries (~1 m thick).

g) metapsammite with calc-silicates and interbedded metapelite containing numerous quartz veins (~3 m thick) * Au bearing.

h) arsenopyrite-rich metapelite with very minor quartz vein development; very tight isoclinal upright folding with arsenopyrite porphyroblasts parallel to cleavage and long axis extended parallel to fold axis (~4 m thick) * Au bearing.

i) metapsammite with calc-silicates and interbedded metapelite containing numerous quartz veins, locally late crosscutting shear fractures are common (~7 m thick) * Au bearing.

j) calc-silicate bearing staurolite-rich metapelite with interbedded metapsammite; quartz veining is not prominent (>10 m).

Although the stratigraphy is uncertain, inversely graded porphyroblast-bearing beds suggest that much of the succession youngs towards the south. Outside the confines of the pit, remnants of cross-stratification are still evident (Fig. 4a). Within the pit area crossbeds become less obvious and take on the appearance of rootless folds (Fig. 4b).

All host rocks and veins within the confines of the pit area contain variable amounts of associated sulphides. Pyrrhotite and arsenopyrite are common in metapsammite horizons as disseminations and flattened lenses along the foliation planes. Arsenopyrite porphyroblasts in these rocks are usually, although not always, adjacent to wider stratabound and stratiform quartz veins. In the most siliceous horizons arsenopyrite as porphyroblastic disseminations becomes the dominant sulphide. All metapelitic units have abundant arsenopyrite, pyrrhotite and pyrite of at least two distinct generations. However, metapelite units associated with abundant calc-silicates have low sulphide content with pyrrhotite more abundant than arsenopyrite. Visible gold, associated sulphides and quartz veins are less abundant in these calc-silicate bearing sulphide deficient units. Other recognized sulphides including galena, sphalerite and chalcopyrite occur either within or immediately adjacent to stratiform and stratabound quartz veins.

Vein Types

At Cochrane Hill six different types of quartz veins (Tables 1 and 2) have been recognized based on textures, mineralogy and crosscutting structural relations. Relative age relations between individual vein types is often difficult to observe because most veins in the mine area are concordant to stratification. Gold has been found in all vein types (Table 1) except type D (flat angular, cross or side veins) suggesting polygenetic mineralization. All veins are strongly deformed except type F (Tables 1 and 2). A description of the six vein types follows. The reader is referred to Haynes (this volume) for a typomorphic description of veins in greenschist facies rocks.

TYPE A - STRATIFORM MICRO-CROSSLAMINATED VEINS

Thin micro-crosslaminated stratiform veins (Fig. 4c) are found scarcely distributed throughout the pit, mainly within the thinly bedded mixed lithology. These veins consist mainly of quartz, but have variable amounts of plagioclase, biotite, tremolite/actinolite, garnet and wall rock inclusions. Minor amounts of observed ore minerals include gold, arsenopyrite, pyrite and pyrrhotite. Most of these veins have a thin median plane which contains the majority of the dark silicate minerals. The ore minerals lie both along the median surface and adjacent to the vein wall.

Individual laminae frequently terminate in one direction giving the appearance of cross-stratification, however, some laminae are observed to intersect each other leading the author to believe that they represent shear planes with each lamina representing successive increments of shear (Norris and Barron, 1968). Relative crosscutting age relations suggest that these veins formed either late in the sedimentation cycle or early in the Acadian deformational history. These shears produced laminae which occurred parallel to bedding planes probably developed while the Meguma Group sediments were still subhorizontal as a response to the first regional folding F_s (O'Brien, this volume).

TYPE B - STRATIFORM/STRATABOUND VEINS

Type B stratiform/stratabound veins form the dominant vein type at Cochrane Hill. They range in thickness from several millimetres up to 30 cm with most veins averaging between 5 cm and 10 cm. The exposed strike length of many of these veins exceeds 30 m. These veins commonly occur between metapsammite beds in the more competent units of the pit area. Where thin metapelite occurs between these beds, the veins often crosscut the metapelite, but do not observably cut the bounding metapsammite. These veins have a central core or median plane filled with tremolite/actinolite (Fig. 4d) with associated plagioclase, alkali feldspar, biotite, muscovite and locally minor garnet. Although quartz is the dominant mineral in these veins, locally they resemble pegmatitic textures. Ore mineralogy in the veins includes gold, arsenopyrite, pyrite, pyrrhotite and minor chalcopyrite, galena and various manganese minerals. Commonly thin laminae, rich in garnet and biotite, form pervasive halos along the outside of these veins. Arsenopyrite pseudo-porphyroblastic growth is also pervasive around these veins. Where type B veins occur in thick metapelitic units silicate minerals other than quartz are not as common and the median plane is often not developed. Adjacent to these veins both garnet porphyroblasts

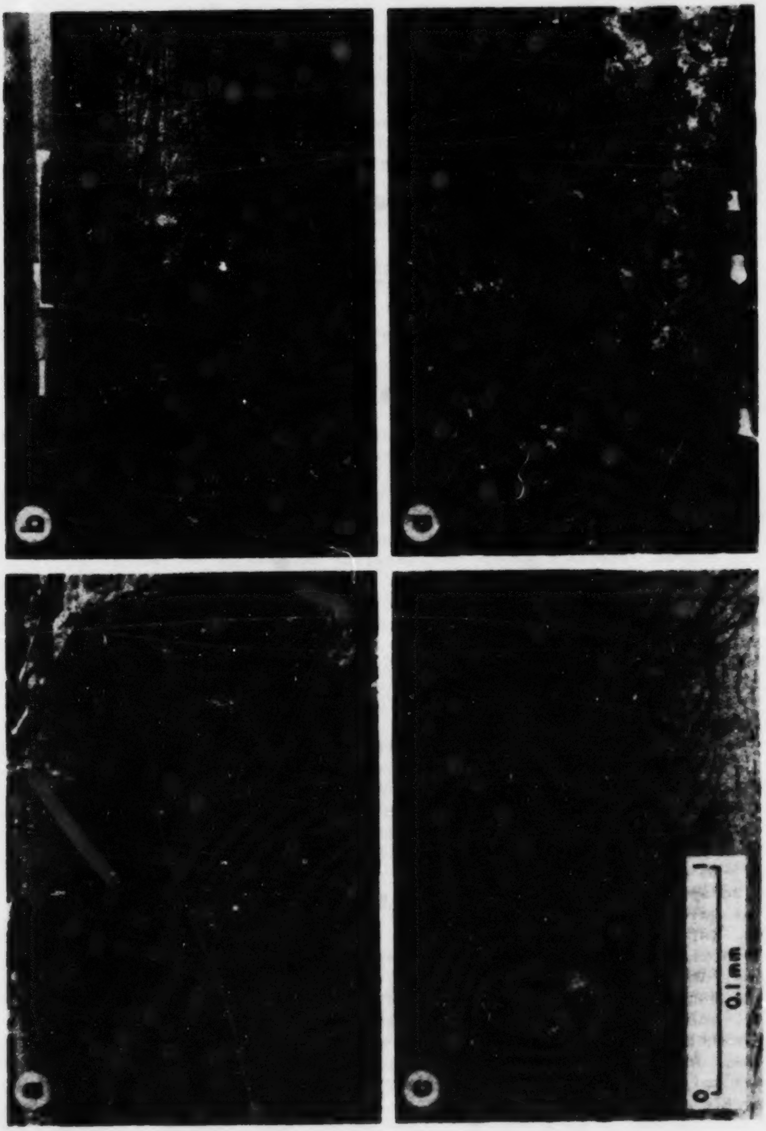

b
0
0.1 mm

Figure 4

a) Photograph from outside the Cochrane Hill mine site showing cross-stratification in deformed metapsammites of the Goldenville Formation. Stratigraphic tops are towards the right-hand side of the photograph. A subhorizontal cleavage is apparent in the upper left of the photograph.

b) Highly deformed cross-stratification(?) from the North Wall of the pit area. The folded foresets have the appearance of rootless folds. The attenuated beds may young towards the top of the photograph and the pen.

c) Microscopic laminations in a thin stratiform quartz vein. Locally individual laminae display a horse-tail texture resembling cross-stratification. A larger fracture (centre of photo) separates groups of laminations.

d) A quartz, plagioclase, K-feldspar vein with a central core zone of actinolite/tremolite. A thin zone of biotite and garnet forms the boundary adjacent to the vein. Concentrations of visible gold are usually confined near the actinolite/tremolite or biotite-garnet zones. Secondary carbonates, sulphates(?) and sulphides occur along joint surfaces.

Table 1. The six vein types at Cochrane Hill and their associated mineralogy based on field observations. Gold is most commonly found in vein types B, C, E and F. The relative age of veins (Table 2) from oldest to youngest are A to F respectively. Types B and E have mineralogy similar to granite pegmatites and thus the name "pegmatoid" is adapted for type E. Also type E has an apparent genetic relationship with deformed granite pegmatites around the mine area.

	VEIN TYPE	SILICATE MINERALOGY	ORE MINERALOGY	
F	ac veins	qu ± (ca)	± Au ± Asp	YOUNGEST
E	Crosscutting pegmatoid quartz veins	qu + kf + pl + mu + bi + ad ± gt ± incl	Au ± Po ± W	↑
D	Flat angular, cross or side veins	qu + bi + gr ± incl	Py + Po	
C	Bedding parallel veins post-regional static metamorphism	qu + bi ± mu ± kf ± pl ± gt	Au + Asp + Py + Po ± Cp ± Sp ± Ga	
B	Stratiform/stratabound veins	qu + kf + bi + mu + pl + ac ± gt	Au + Asp + Py + Po ± Cp ± Sp ± Ga	↓
A	Stratiform micro-cross-laminated veins	qu ± pl ± bi ± ac ± gt ± incl	± Au ± Asp ± Py ± Po	OLDEST

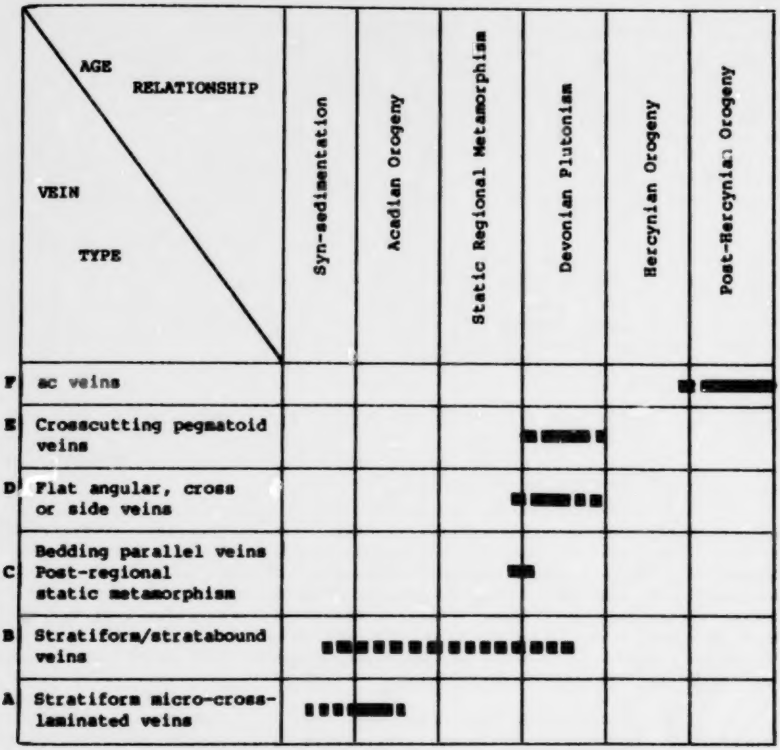
KEY TO SILICATE MINERALOGY
qu - quartz
kf - alkali feldspar
bi - biotite
mu - muscovite
ac - tremolite/actinolite
ad - andalusite
pl - plagioclase
gr - graphite
gt - garnet
incl - inclusions

KEY TO ORE MINERALOGY
Asp - arsenoprite
Au - gold
Cp - chalcopyrite
Ga - galena
Po - pyrrhotite
Py - pyrite
Sp - sphalerite
W - scheelite

ca - carbonate

(Figs. 5 and 6a) and arsenopyrite pseudo-porphyroblasts are seen to overgrow or crystallize with gold. This suggests the possible existence of gold prior to the onset of the regional static metamorphism which produced the garnet porphyroblasts. This may also suggest the existence of the vein prior to regional metamorphism although vein/porphyroblast relationships are generally obscure in the field. The age of these veins (Table 2) is shown to range from possibly as early as syn-sedimentation to as late as Devonian plutonism. Type B veins have been affected by the Hercynian Orogeny and possibly the Acadian Orogeny to form tight upright folds (Fig. 7a) as well as extensive boudinage (Fig. 7b). The high gold content in many of these veins makes them probably the most significant vein type at Cochrane Hill.

Table 2. This table shows the relative age relationship of various vein types (Table 1) at Cochrane Hill. Although most veins at Cochrane Hill are type B, a complete range in ages is present. Broken lines indicate the limits of uncertainty.



Based on the predominantly stratabound nature of type B veins it is the author's interpretation that they resulted from hydrothermal solutions emplaced into strata after folding began.

TYPE C - BEDDING-PARALLEL VEINS

Mineralogical and textural relations of type C, bedding-parallel veins lead them to be one of the most interesting vein sets at Cochrane Hill. These auriferous veins (Fig. 6b), are parallel to bedding planes (stratiform) as far as they can be traced along exposures in the pit, but

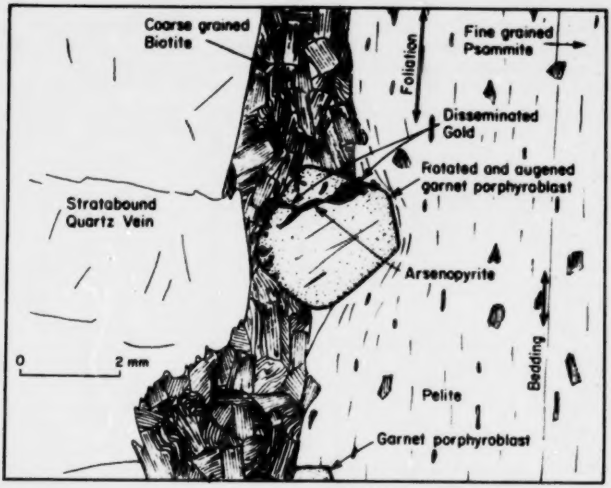

Coarse grained Biotite
Fine grained Psammite
Foliation
Disseminated Gold
Rotated and augened garnet porphyroblast
Stratabound Quartz Vein
Arsenopyrite
0
2 mm
Bedding
Pelite
Garnet porphyroblast

Figure 5. Rotated and augened garnet porphyroblast associated with coarse grained biotite adjacent to stratabound quartz vein. Note the overprinting of earlier or contemporaneous gold and arsenopyrite by garnet. To accompany Figure 6a.

crosscut regional static metamorphic porphyroblasts (Figs. 6c and 8). Type C veins are thin and invariably bordered by zones of dark coloured slaty lithology. Gold in these veins is normally found at the boundary between the wall rock and vein. Minor boudinage along these veins is common due to later Hercynian deformation. Micro-crosslaminations similar to those in type A veins are locally preserved where recrystallization has not destroyed them. Thin bands of foliated wall rock inclusions parallel to the vein wall are common throughout.

Mineralogically the veins are rich in sulphides, particularly pyrrhotite, and have significant gold (Table 1). Quartz and biotite are the characteristic silicate minerals with muscovite, alkali feldspar, plagioclase and garnet as minor constituents concentrated in clusters along the vein walls.

The relative age of type C veins is restricted from late in the regional static metamorphic history (cuts metamorphic garnet porphyroblasts) to pre- or early syn-Devonian plutonism (type C crosscut by folded type D veins). The interpretation presented here for the formation of these veins is that solutions associated with amphibolite grade metamorphism remobilized existing metals in the wall rocks from depth and then precipitated them later at appropriate sites closer to the erosional surface. Alternatively these solutions may have represented early formation waters associated with the onset of granitic plutonism in the area.

TYPE D - FLAT ANGULAR VEINS

Flat angular, cross or side veins (see Haynes for morphologic description, this volume) occur sporadically throughout the pit area (Fig. 7c) but do not form a volumetrically significant vein type. They crosscut vertical beds at a high angle making them best exposed on the steep faces of the pit walls. Like most veins at Cochrane Hill, they have an east-west strike. Mineralogically these veins consist essentially of quartz with minor amounts of biotite, graphite (or ilmenite?) and wall rock inclusions. Pyrrhotite and pyrite are the only observed sulphides and gold has not been seen in this vein type. These veins crosscut type C bedding parallel veins and are folded into minor upright open folds by the Hercynian Orogeny (Fig. 7d). The age of the veins is therefore approximately concomitant with either the late warning stages of regional amphibolite grade metamorphism or the early stages of Devonian plutonism.

TYPE E - CROSSCUTTING PEGMATOID VEINS

Occurring through the central portion of the pit as well as outside the confines of the pit are relatively wide (5-30 cm), east-west striking, andalusite-bearing veins, locally deformed into tight upright subhorizontal folds. These veins show extensive boudinage where they lie subparallel to bedding. The mineralogy of type E veins includes quartz, alkali feldspar, plagioclase, muscovite, biotite and andalusite with minor amounts of garnet and wall rock inclusions (Figs. 6d and 9a). Variations of relative mineral abundance and grain size gives true pegmatitic textures to some portions of the veins. Alumino-silicate minerals, particularly andalusite, characterize these predominantly quartz-rich veins. Ore mineralogy includes gold with minor amounts of pyrrhotite and a trace of scheelite. Disseminated gold is found along the entire strike length of type E veins in the central part of the open-pit (La France, personal communication, 1982). Because of the pegmatitic texture of some parts of these veins, as well as the close spacial association with granite pegmatite sheets outside the pit area, they are presumed to be related to a Devono-Carboniferous granitoid intrusion. Type E veins and the true pegmatites may represent distinct age groups of a granitic intrusion which is presumed to lie below the Cochrane Hill deposit.

TYPE F - AC VEINS

The last vein type discussed here is veins which crosscut all upright east-west trending structures at high angles. Because of this relationship to the major folds they are designated "ac" veins or stringers. These north-south trending type F veins crosscut all strata and other vein types but are not themselves deformed (Fig. 10a). Occurring in swarms, they are generally thin and dip steeply towards the west. In less competent metapelites these veins often displace both earlier veins and wall rocks (Fig. 10b). In more competent metapsammites type F veins are less prominent and occur mainly as small stringers with lighter coloured alteration halos. Fibrous quartz perpendicular to the vein walls is locally observed. Quartz composes most of these veins with carbonate found in some (Table 1). Gold and/or arsenopyrite are also common along some of the smaller type F veins. The age of these veins is post-Hercynian Orogeny because they are undeformed. Late movements along the Minas Geofracture may be responsible for their development.

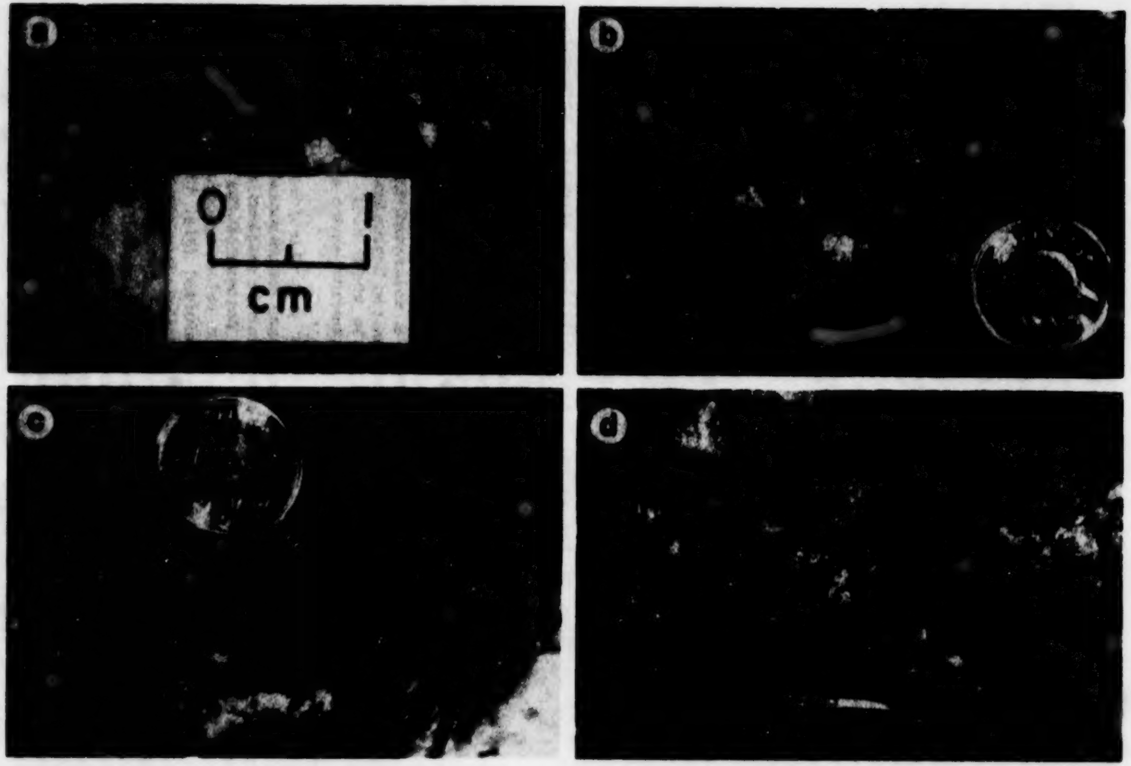

a
0
1
cm
b
c
d

Figure 6

a) Large garnet porphyroblasts with associated coarse biotite adjacent to stratabound quartz vein. Central garnet porphyroblast contains free gold as fine disseminations and as a massive zone running perpendicular to the quartz vein (right-hand side of porphyroblast). The precipitation of the gold is believed to be pre- or syn-garnet porphyroblast growth. Similar features are observed in numerous arsenopyrite crystals.

b) Photograph of thin stratiform vein surrounded by a characteristic dark dense slate. Two sites of visible gold occur adjacent to the vein wall (arrows). Adjacent to the vein is a zone of dense dark slate. The contact with the metapsammite is sharp. Arsenopyrite is common in the metapsammite. This sample comes from the North Bench of Figure 2.

c) Photograph showing thin stratiform gold-bearing quartz vein crosscutting regional, static metamorphic, garnet porphyroblasts. These veins are discordantly cut by a barren quartz vein in the lower right-hand corner. The mineralogy of the stratiform vein cutting the garnet porphyroblasts is different from the stratiform veins below it. Sulphides define the cleavage in the metapsammite adjacent to the stratiform veins.

d) Boundinaged quartz, plagioclase, K-feldspar vein in thinly bedded metapsammite. Minor arsenopyrite alteration adjacent to margins. Veins typically are stratiform or stratabound and may contain andalusite, biotite and muscovite. This vein texture is uncommon in pelitic horizons.

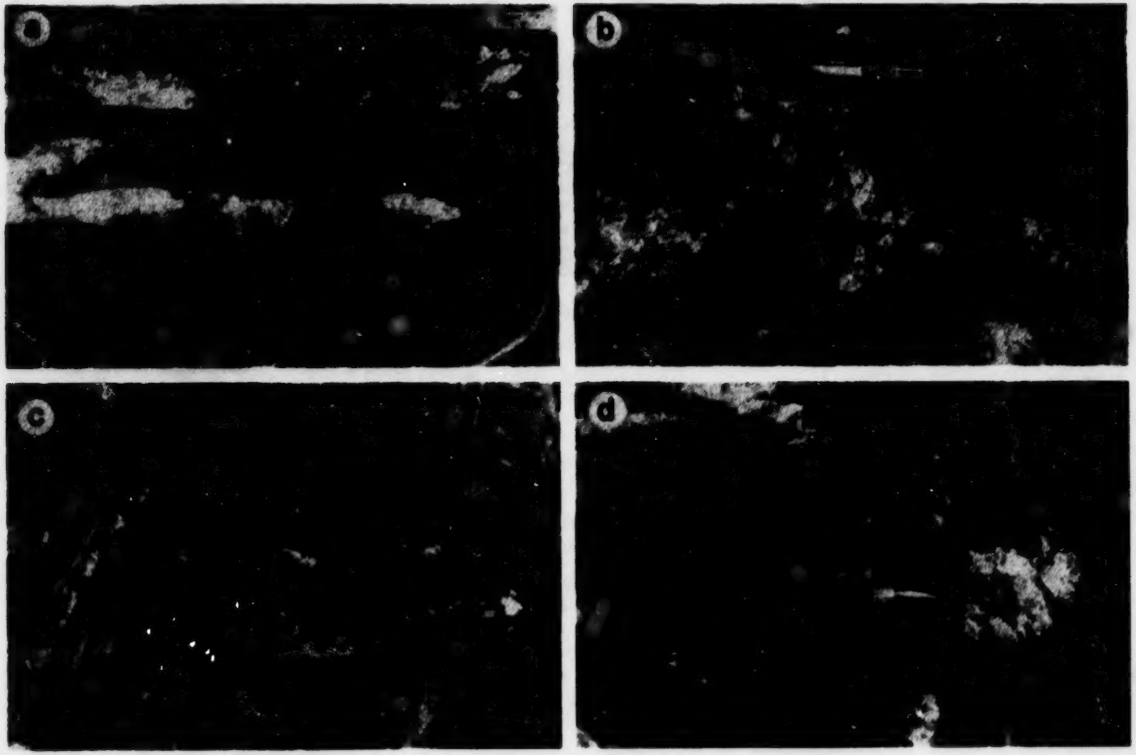

a
b
c
d

Figure 7

a) Type A laminated quartz vein (A) in mixed metapelite and very fine grained metapsammite. Crosslaminations in the fine grained metapsammite (centre right of photograph) indicate that the general younging direction is upwards. Vein laminations are observed in the central portion of the photograph. Undeformed type F "ac" veins crosscut earlier folds.

b) Type B stratiform/stratabound quartz rich vein with arsenopyrite mineralization in the metapsammitic wall rock along the bottom of photograph. Vein shows extreme boudinage with the thinned neck towards the right hand side of photograph. Plagioclase, K-feldspar, actinolite and biotite constitute the dominant mineralogy where the vein begins to decrease in thickness.

c) Type D flat angular vein (D) in southeastern wall of pit. Along the left side of the photograph where the vein lies close to bedding (S_o), minor boudinage is exhibited. Small F_M fold in centre of photograph (Fig. 7d).

d) Type D flat angular quartz vein (D) deformed by F_M fold. Fanning axial planar cleavage (S_M) in quartz vein. Bedding (S_o) in metapsammite is vertical. In the bottom-left portion of the photograph is a type C bedding parallel vein (C) cut by type D vein.

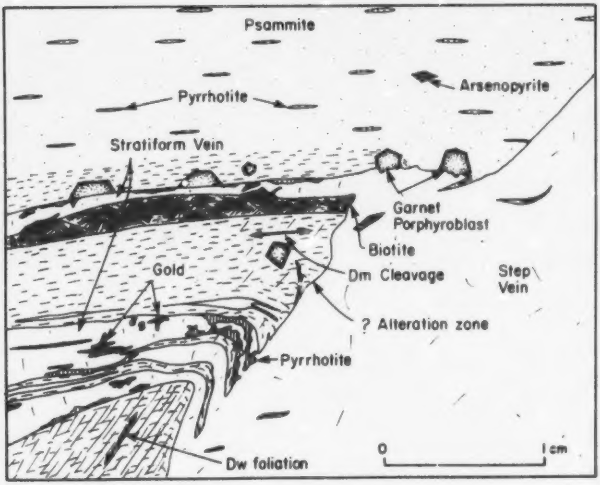


Figure 8. Garnet porphyroblasts cut by stratiform auriferous quartz veins in turn crosscut by a later step vein. Note the apparent alteration associated with the stratiform vein. To accompany Figure 6c.

STRUCTURE

The structure of the northern domain is complex and is only briefly discussed below. The general age relations and features of these events as well as the associated vein history are summarized in Table 2. The history of the early Acadian structures from the southern domain are discussed by both O'Brien and Keppie (this volume). A description of the later overprint structures on granitic rocks is also discussed.

Overprint Deformation

At Cochrane Hill two cleavages deform and augen pre-existing Acadian structures as well as metamorphic index porphyroblasts. Similar structures have been reported from Mount Uniacke and Lower Sackville near Halifax (Smith, 1983). These overprint deformations in the Cochrane Hill area are herein designated as D_W, for Waternish and D_M, for Melrose; locations where they are well exposed. These structures are best observed in less competent metapelite units where all or most of the earlier structures are destroyed. In the more competent metapsammite beds the earlier structures are often preserved. Windows into Acadian structures occur on the scale of individual beds (Figs. 10c and 11). Two foliations also deform the Devono-Carboniferous Bull Ridge pluton (Chevalier, 1983) suggesting that the overprint deformation postdates the plutonism in the northern domain (Fig. 12).

D_W DEFORMATION

The first overprint deformation to deform Acadian structures in the northern domain is designated D_W for an exposure in the Waternish Sycline on the No. 7 highway south of Cochrane Hill. Here, a well developed spaced foliation dipping steeply northwards augens chiastolite porphyroblasts. In the open-pit at Cochrane Hill S_W cleavage is developed as a moderately steep, northward dipping, east-west striking, spaced muscovite-biotite foliation (Fig. 10d) with a shallow westward pitching intersection lineation on the bedding. Although this foliation is widespread throughout the mine area, it is best observed on the southern wall of the pit. Here, it deforms and augens index porphyroblasts as well as arsenopyrite pseudo-porphyroblasts. Locally S_W foliation resembles steepened S_C cleavage (see O'Brien, this volume). Minor F_W folds are not common around the mine area. However, folded types B and C veins are observed to have an associated S_W cleavage where they occur in thinly laminated metapelites. A minor fold (Fig. 9b) in the brook crossing the No. 7 highway in the Waternish Syncline is regarded by Keppie (this volume) as an F_W fold (Fig. 9b).

D_M DEFORMATION

The D_M (Melrose deformation)related structures are named for their overprint relationships between Melrose and Cochrane Hill. At Cochrane Hill an east-west striking, steeply northward dipping crenulation cleavage, (S_M) lies subparallel to bedding and deforms and augens muscovite and biotite minerals in the earlier S_W cleavage. New muscovite growth defines the S_M cleavage planes. Exposures of the D_M type section will be more fully described in a later publication. In the pit area D_M folds are not common, but are observed to fold type D veins (Fig. 7d). The intensity of development of S_M cleavage is sporadic (Fig. 10c) and best developed in the metapelite units. S_M cleavage also augens earlier developed folds (Fig. 9d). Boudinage and fold limb attenuation is also associated with this deformation. One of the larger F_M folds is exposed west of the St. Marys River, west of Cochrane Hill, where S_W cleavage and bedding are observed to be folded together (Fig. 9c). However, this fold may possibly represent a tightened Acadian fold structure.

LATE FOLDS

Several late generations of kink bands and associated crenulations deform all preceding fabrics. Axial planes vary from subhorizontal to vertical. An indepth study of these late folds will be published at a later date.

METAMORPHISM

Peak regional metamorphic conditions at Cochrane Hill show amphibolite grade assemblages characterized by muscovite-biotite-garnet-cordierite-staurolite-andalusite (Fig. 13a, b, c). These minerals presumably represent the static metamorphism associated with the Acadian Orogeny throughout the rest of southern Nova Scotia (Taylor and Schiller, 1966). In the northern domain, the Acadian cleavages are defined by

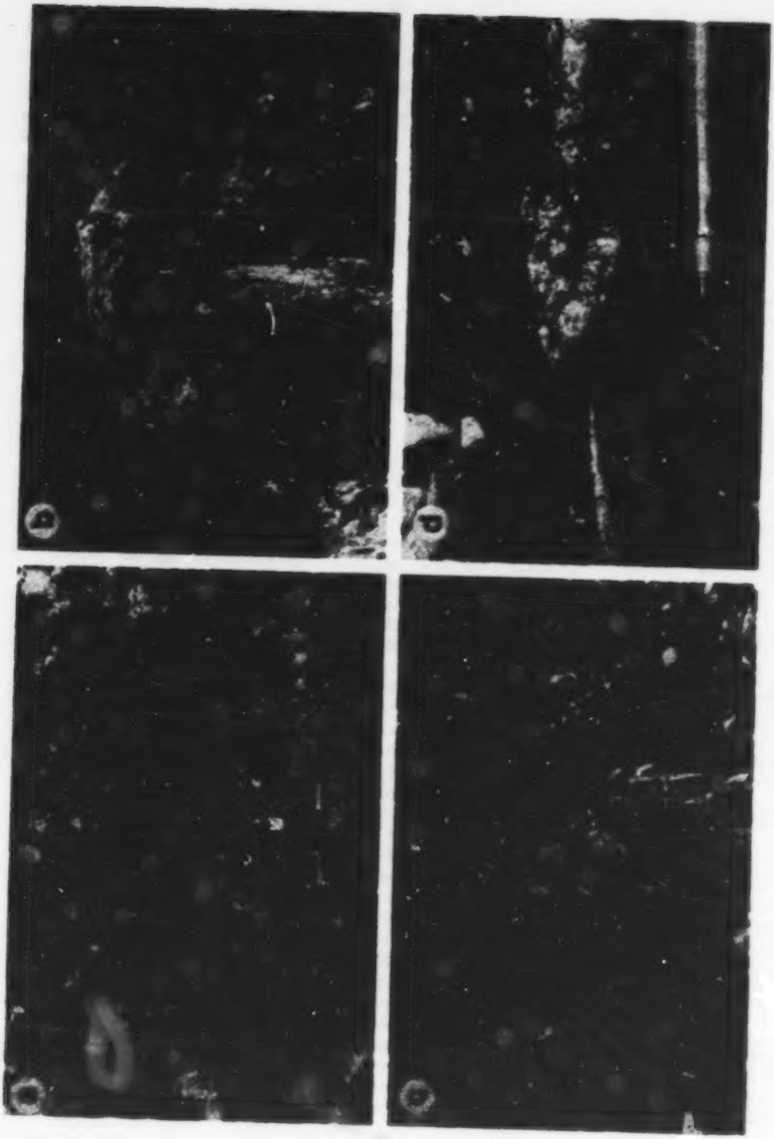


Figure 9

a) Coarse grained pegmatoid vein with characteristic large andalusite crystals as well as muscovite, plagioclase, K-feldspar, quartz and minor amounts of biotite. A large andalusite crystal occurs at the right centre of the photograph.

b) Mesoscopic fold south of Cochrane Hill in semipelitic rocks of the transition zone separating the Goldenville and Halifax Formations. The asymmetric fold is deforming a crenulation cleavage. The nearly vertical axial cleavage, S_M, is strongly developed along the attenuated southern limb of the fold. Flat lying crenulation cleavage is observed in the central-left portion of the photograph next to the water.

c) Mesoscopic fold in metapsammites west of Cochrane Hill. The fold is best defined by a thin polydeformed calc-silicate bed to the right of the hammer. The axial planar cleavage defining the fold is S_M. The fold axis is gently westward plunging, into the photograph.

d) Minor F_M (or earlier) fold with a vertical fold axis in a stratabound quartz vein in staurolite-bearing metapelite. Note the extreme attenuation in the fold limbs and thickening in the hinge area. Locally the hinges become detached and form isolated lenses resembling boudins. S_M crenulation cleavage augens the fold hinge area and attenuates the fold limbs.

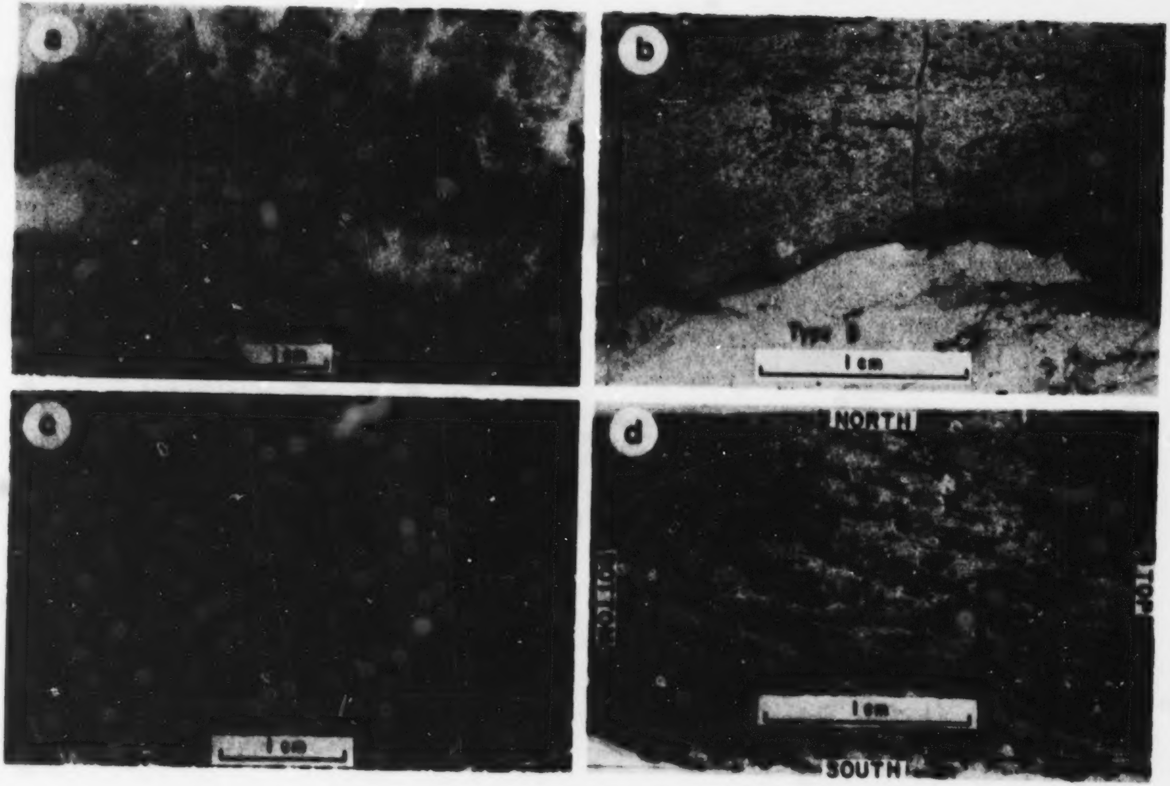

a
1 cm
b
Type b
1 cm
c
1 cm
d
NORTH
TOP
BOTTOM
1 cm
SOUTH

Figure 10

a) Type C bedding parallel veins in dark thinly laminated metapelite. These veins are crosscut by undeformed type F ac-veins. Both type C veins and bedding laminations are offset by younger ac veins. In the upper left portion of the photograph the bedding parallel vein crosscuts a garnet porphyroblast. Gold mineralization (Au) occurs in the centre of the photograph in the type C vein. Arsenopyrite mineralization along the bottom of the photograph is restricted to a thin zone of finely laminated metapelite.

b) Type F ac-veins crosscut metapelite laminations at right angles in the right central portion of the photograph. The veinlet is filled with arsenopyrite (black). A type B stratiform/stratabound vein cuts biotite metapelite in the lower portion of the photograph.

c) Heterogeneous development of upright S_M crenulation cleavage deforming flat lying spaced S_C crenulation cleavage. S_M is developed throughout although several zones show preferential development. These zones show extensive rotation of S_C cleavage. Staurolite (St) and garnet (Gt) porphyroblasts are augened by the S_M cleavage.

d) Photomicrograph of biotite-garnet metapelite from Cochrane Hill. The S_W spaced crenulation cleavage is defined mostly by biotite and minor muscovite. The S_W cleavage is deformed by vertical S_M schistose cleavage. Note the new biotite growth around some of the biotite porphyroblasts.

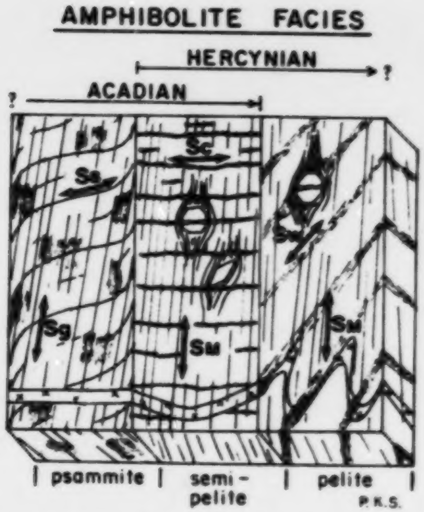


Figure 11. Schematic block diagram portraying the heterogeneous deformation displayed in selected varied amphibolite facies rock lithologies in the Cochrane Hill area. The most competent lithologies (metapsammite) were most intensely deformed during the Acadian Orogeny and show both S_c flat cleavage and S_g parting or locally pressure solution cleavage. The least competent lithologies (metapelite), which contain numerous regional static metamorphic porphyroblasts, have been deformed by overprinting Hercynian(?) structures, first by S_W and then by S_M. Here porphyroblasts are augened and most earlier structures are destroyed. In intermediately competent beds (meta-semipelite) both Acadian and Hercynian(?) structures are locally recognised. These variations may occur on the scale of individual beds.

muscovite and biotite. The overprint cleavages are also defined by muscovite and biotite (S_W by both micas, S_M by muscovite only).

Thin, compositionally distinct, dark lithologic bands throughout the pit area are particularly prominent adjacent to some stratabound veins and in the calc-silicate bearing metapelite units. Original sedimentary laminae are now observed as metamorphic porphyroblast-rich laminae. These thin alternating bands may be characterised by one or several porphyroblastic minerals. Many of the large garnet porphyroblasts (Fig. 8) occur adjacent to quartz veins along distinct laminae reflecting possible original composition. The veins also have apparent high temperature, possibly

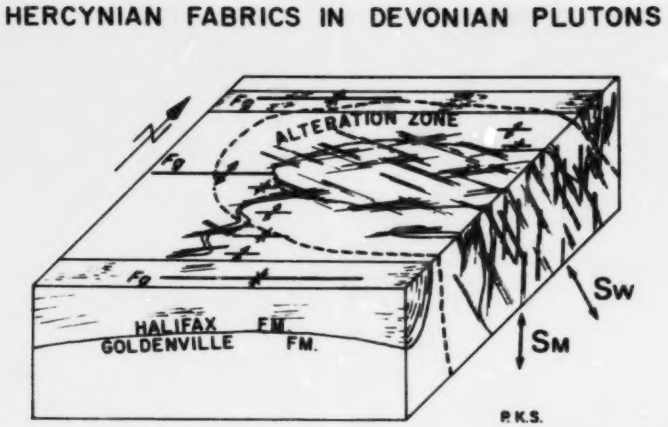


Figure 12. Schematic block diagram showing intrusive Devonian(?) granite (Bull Ridge pluton) east of the Cochrane Hill gold deposit. This granite crosscuts Acadian F_g structures and is itself deformed by overprint S_W and S_M foliations. Associated pegmatites also show similar structures. The alteration zone is represented by K-feldspar metasomatism. S_W and S_M are very intense in Halifax Formation synclines.

metamorphic, mineral assemblages including feldspars, garnet and tremolite/actinolite. These mineral assemblages which are normally asymmetric across the stratiform/stratabound veins reflect metamorphic zonation in the thinly laminated veins suggesting a possible syn-sedimentary origin. Organic matter (now graphite) may have been in part responsible for the extraction of some metals, including gold, during slow sedimentation.

GOLD DISTRIBUTION

At Cochrane Hill visible gold occurs in a number of sites with significant regularity. These are as follows:

1) adjacent to types B and C (Table 1) quartz veins in coarse grained biotite/garnet-rich laminae; the gold varies from being platy and crenulated, sandwiched between deformed biotite grains, to irregular disseminations.
2) within type B quartz veins, gold commonly occurs as irregular disseminations within the actinolite/tremolite rich median section.
3) in and adjacent to type C quartz veins; these veins are often rimmed by dark dense metapelite which is rich in graphite and ilmenite; in some places the gold protrudes into the pelitic host rock.

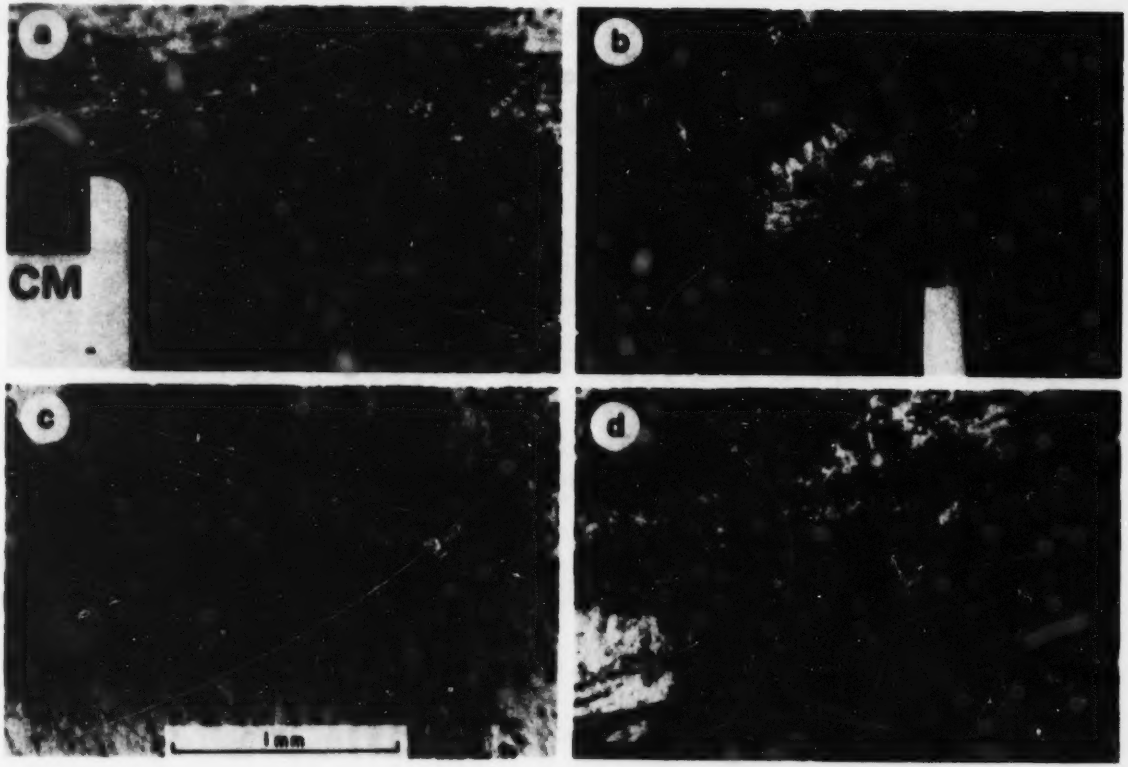

a
CM
b
c
1mm
d

Figure 13

(a) Photograph of granular staurolite, garnet, muscovite, biotite metapelite from southern wall of the Cochrane Hill open-pit. Staurolite porphyroblasts are augened by later Hercynian cleavages.

(b) Large chiastolite porphyroblast in semipelitic schist of the Halifax Formation just south of Cochrane Hill. Garnet and minor staurolite occur in association. These porphyroblasts are augened by younger Hercynian cleavages.

(c) Photomicrograph of staurolite, garnet, biotite, muscovite, quartz schist. Both staurolite (on right) and garnet (centre left) are poikiloblastic. Numerous small tourmaline crystals occur throughout. Garnet porphyroblast shows minor augening by muscovite.

(d) Stratabound boudinaged quartz, plagioclase, K-feldspar vein (lower part of photo) with arsenopyrite alteration halo along the top side of the vein. These veins are typically found in the metapsammitic units and have preferential arsenopyrite development along one side of the vein.

4) as dissemination or inclusions in arsenopyrite porphyroblasts
5) as disseminations in metapelite.
6) as trappings or inclusions in garnet or other silicate porphyroblasts.
7) as stringers and disseminations which crosscut garnet porphyroblasts.
8) in late undeformed ac stringers cutting beds at high angles.

GENETIC MODEL AND DISCUSSION

A variety of genetic models have been proposed to account for the gold distribution in the Meguma Group of Nova Scotia including: biogenic concentration in thin shale laminae during sedimentation and remobilized paleoplacers (Smith, 1981); stratigraphic control within unique horizons (McBride, 1978); hydrofracturing and metamorphic solutions secreted during folding and greenschist metamorphism (Graves and Zentilli, 1982); structural control (Rickard, 1912); lateral secretion (Thorpe and Thomas, 1976); and sedimentary exhalates (Haynes, this volume). Studies of Cochrane Hill suggest that several of these processes may have been active during the deposit's geological history giving rise to a true polygenetic deposit.

Although the primary source of the gold has yet to be conclusively identified, the processes responsible for its precipitation and remobilization started very early in the geological history of the deposit. A tentative genetic model implies that the first event significant to the gold history of Cochrane Hill occurred during the deposition of mixed shales and sandstones. During quiescent deposition of thinly laminated thick shale units, metals were extracted by biogenic organisms. The abundant graphite in wall rocks adjacent to the auriferous quartz veins probably represents the metamorphosed organic remains. This process could account for the prominent metal rich metapelites at Cochrane Hill and other gold deposits throughout the Meguma Terrane. Although vein formation during sedimentation has not yet been conclusively documented some of the observed layering in stratiform veins at Cochrane Hill may reflect original compositional laminae.

The next recognized event in the gold history proceeded contemporaneously with or just subsequent to the deposition of the Goldenville Formation. Bedding parallel shear (Norris and Barron, 1968) produced relatively thin, micro-crosslaminated stratiform (type A) quartz veins (Fig. 4c). These veins locally contain wall rock inclusions and display a ribbon to streaky texture. Each micro-crosslamination represents an individual shear plane (Fig. 14) produced during layer parallel shear (Norris and Barron, 1968). Lateral secretion of metals, including gold, into these shear zones probably occurred while the beds were still subhorizontal. These crosslaminated veins were subsequently deformed by Acadian folding. Veins possessing a ribbon texture have been recognized throughout Nova Scotia to have historical importance for carrying gold and associated metals.

The next important veining event at Cochrane Hill produced type B stratiform/stratabound veins (Table 1) with associated arsenopyrite alteration zones (Fig. 13d). This vein type is predominant in the more competent

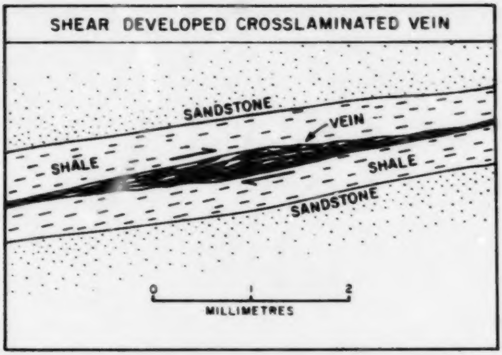


Figure 14. Schematic cross-section showing development of crosslaminated texture of stratiform quartz vein by shear parallel to bedding. Individual laminae represent planes of shear. This texture is observed in veins that developed prior to significant folding as well as in veins that postdate regional static metamorphism.

metapsammitic units (lithological units b, e and i). The mineral assemblage and alteration zone suggest the veins formed or were at least influenced by relatively high temperatures. The high temperature is most likely an effect of a hydrothermal fluid system or metamorphic overprinting. Preliminary microprobe analysis using arsenopyrite crystals containing loellingite (Kretschmar and Scott, 1976) from this vein type suggest a formation temperature of ≈550°C or greater. Gold is common both within and adjacent to these veins and locally forms high grade ore.

Crosscutting these veins are thin, locally folded, type C bedding parallel veins which postdate the regional static metamorphism. These veins cut biotite, garnet (Fig. 6c) and staurolite porphyroblasts. They contain numerous sulphides and have abundant associated gold. A fine grained dense, dark slate, characteristically about 1 cm wide generally occurs adjacent to these veins. This dark slate is thought to represent the product of desilicification of the wall rock. Type D flat angular quartz veins with little or no metal content cut type C veins. Types C and D veins are inferred to be the result of one or more of the following three processes: 1) solutions derived during metamorphism, 2) continuation of the proposed hydrothermal system which produced type B veins, and 3) early solutions associated with the production of plutonic rocks.

Type E crosscutting quartz, K-feldspar, plagioclase, muscovite, biotite, andalusite bearing veins which have a pegmatitic texture (Fig. 9a) and a close spacial distribution with sheeted granite pegmatites occur both in and outside the mine area. This common vein type probably represents a phase of the granite plutonism in this area and is suggestive of a buried pluton below Cochrane Hill (Fig. 15) . These veins from the mine area contain gold within and adjacent to them with the larger veins carrying visible gold the entire length of the mine area. The gold in these veins has

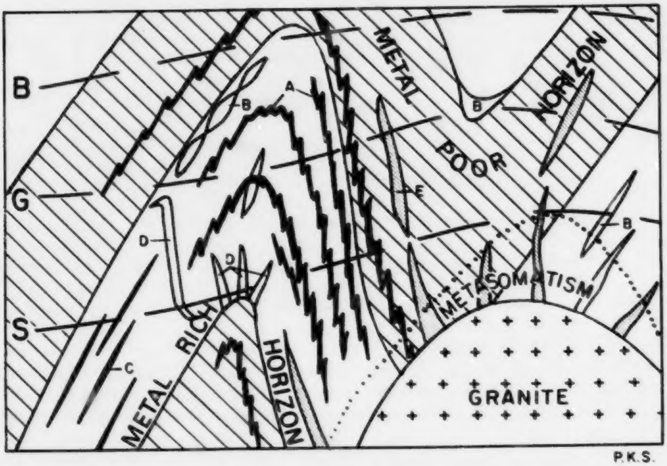


Figure 15. Schematic diagram showing different veining events during the Acadian Orogeny. Stratiform and stratabound veins which formed prior to folding (black) mimic the folding. Some of the veins developed during folding include boudinaged A_g veins (A), tensional veins in fold limbs (B), tensional veins in fold hinges (C), and rare saddle veins in fold hinges (D). Later crosscutting granitic rocks have associated pegmatites (E), and pegmatoid quartz veins (F). Thin stratiform veins which cut static metamorphic porphyroblasts (G), may be from metamorphic solutions. Most veins at Cochrane Hill may be of type "F" and "G". In the northern domain later folding has modified all veins.

been remobilized and it is therefore difficult to determine whether the gold has crystallized from the parent magma or been incorporated in the pegmatite veins from the wall rocks.

The existence of quartz, arsenopyrite and gold in small, undeformed type F veins and stringers suggest that gold was remobilized after both the granitic intrusion and the intense overprint deformation. These veins and stringers, as well as associated kink bands and shear zones, probably resulted from movements along the Minas Geofracture to the north.

CONCLUSIONS

The main conclusions reached as a result of the field observations follow:

1) There is a cyclic succession of lithologies across the Cochrane Hill pit area, which may reflect stratigraphic or structural repetition.

2) There are at least six different types of quartz veins represented at Cochrane Hill based on silicate and ore mineralogy as well as form.
3) There are not less than four stages of gold remobilization or enrichment.
4) Both Acadian and overprint structures are present; the former preserved in windows of strain augen on the scale of individual beds.
5) At Cochrane Hill a polygenetic model for ore mineralization is envoked using a) primary sedimentation, b) lateral secretion, c) hydrothermal solutions, and/or d) metamorphic solutions, e) plutonism, and f) minor late stage shearing.

ACKNOWLEDGMENTS

My appreciation is extended to Dr. Bill Young and Northumberland Mines Ltd. for allowing me unlimited access on the property as well as the use of some pumping equipment. Thanks also go to Mr. Oscar LaFrance, mill supervisor, for offering his extensive knowledge of the pit mineralization. A deep appreciative thanks also is extended to Mr. Anthony (Tony) MacDonald for his numerous evening discussions related to gold exploration in the area.

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SEDIMENTARY FEATURES OF SOME GOLDENVILLE FORMATION SANDSTONES, SHERBROOKE AREA, EASTERN NOVA SCOTIA*

J. W. F. Waldron**

The Goldenville Formation in eastern Nova Scotia resembles other Lower Paleozoic greywacke terranes around the world in consisting of monotonous alternations of sandstone and slate. Earlier attempts at lateral correlation and stratigraphic subdivision in the Goldenville Formation have been futile. Previous workers have described the regional variability in the Formation (Schenk, 1970) and measured long vertical sequences (Harris, 1971; Smith, 1981). This note records detailed observations of the vertical sequences within single turbidite beds and packets of beds, some of which suggest peculiarities of the depositional system when compared with typical submarine-fan deposits. Figure 1 shows the locations of well-exposed sections at which most of the data were collected. A simple facies classification is proposed (Fig. 2), which more adequately represents the observed range of sedimentary structures than the simple Bouma sequence terminology used by previous workers.

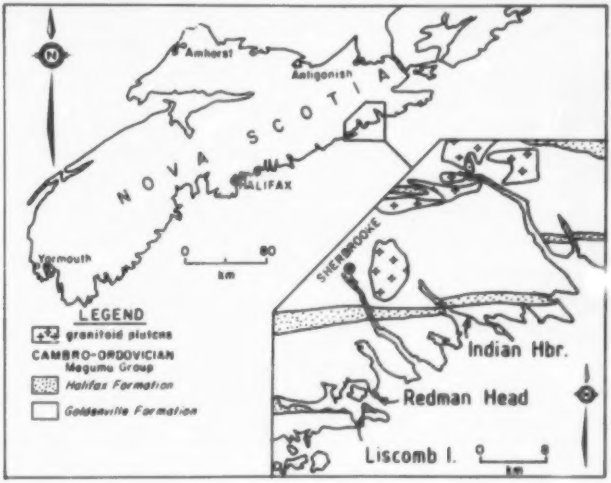
N
Amherst
Antigonish
NOVA SCOTIA
HALIFAX
Yarmouth
0 80
km
LEGEND
granitoid plutons
CAMBRO-ORDOVICIAN
Meguma Group
Halifax Formation
Goldenville Formation
SHERBROOKE
Indian Hbr.
Redman Head
Liscomb I.
0 5
km

Figure 1. Location map, showing position of three well-exposed sections studied.

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*Contribution to Canada-Nova Scotia Co-operative Mineral Program 1981-84. Project carried by Geological Survey of Canada and Nova Scotia Department of Mines and Energy.

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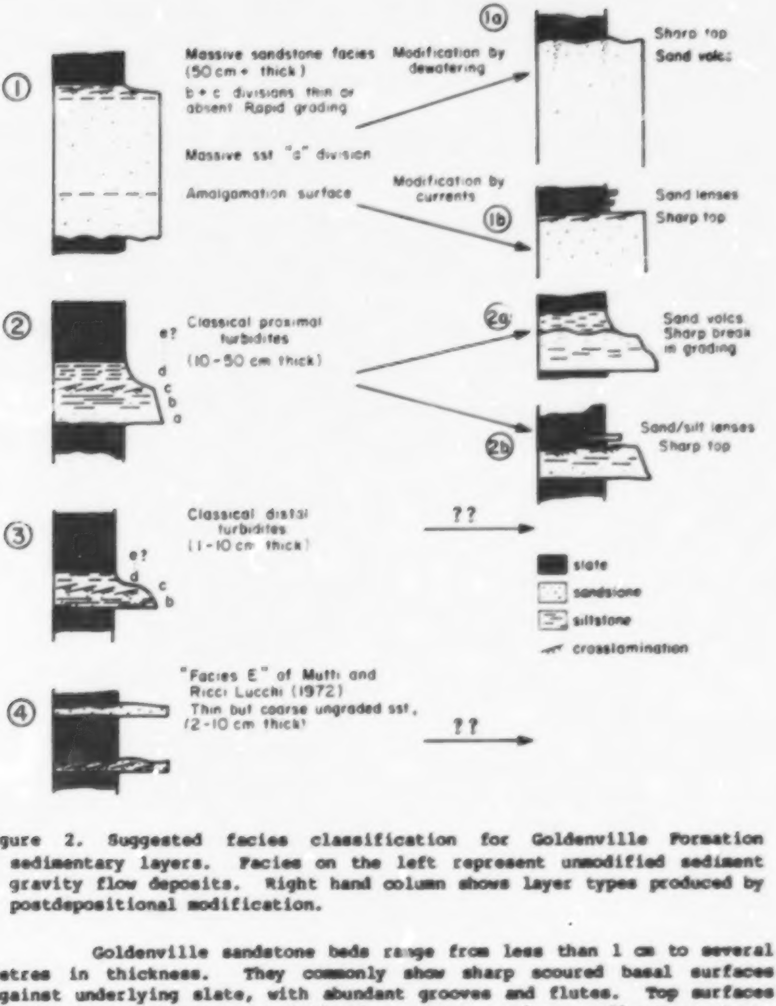

①
Massive sandstone facies (50 cm + thick)
b + c divisions thin or absent. Rapid grading
Massive sst "a" division
Amalgamation surface
Modification by dewatering
1a
Sharp top
Sand volcs
Modification by currents
1b
Sand lenses
Sharp top
②
e?
d
c
b
a
Classical proximal turbidites (10 - 50 cm thick)
2a
Sand volcs
Sharp break in grading
2b
Sand/silt lenses
Sharp top
③
Classical distal turbidites (1 - 10 cm thick)
e?
d
c
b
??
slate
sandstone
siltstone
crosslamination
④
"Facies E" of Mutti and Ricci Lucchi (1972)
Thin but coarse ungraded sst, (2 - 10 cm thick)
??

Figure 2. Suggested facies classification for Goldenville Formation sedimentary layers. Facies on the left represent unmodified sediment gravity flow deposits. Right hand column shows layer types produced by postdepositional modification.

Goldenville sandstone beds range from less than 1 cm to several metres in thickness. They commonly show sharp scoured basal surfaces against underlying slate, with abundant grooves and flutes. Top surfaces of sandstone beds may be gradational or sharp. Primary sedimentary structures include parallel lamination, crosslamination, and slate intraclasts. Postdepositional loading and water-escape produced convolute lamination, pseudonodules, dish structures, pipe and sheet structures, and abundant small (5-20 cm diameter) sand volcanoes. Small sandstone dykes penetrate upwards into overlyng slate at some horizons.

Sandstone beds may be classified into two groups according to the nature of their top surfaces. Beds of the first group are characterized by gradational tops and correspond well with facies described from submarine-fan environments elsewhere. The three intergradational types of Walker (1979) are recognized:

1) **Massive sandstones** are typically 50 cm to 3 m thick, but frequently occur in amalgamated packets (Fig. 2), within which distinct depositional events are difficult to distinguish. Grading is usually confined to the top few centimetres, in which parallel or ripple crosslamination may be present.

2) **Proximal turbidites** are usually 10 cm to 50 cm thick and show complete or partial Bouma sequences with a structureless basal "a" division.

3) **Distal turbidites** are generally thinner and lack the structureless basal "a" division of the Bouma sequence. Thinner beds lack the parallel laminated "b" division also. Distal turbidites are largely confined to slate-dominated intervals within the Goldenville Formation.

These facies are shown diagrammatically in the left-hand column of Figure 2. Types 2 and 3 represent classical turbidites, and type 1 represents massive sandstones which were probably deposited by currents intermediate between true turbidity flow and grain flow (Stauffer, 1967; Lowe, 1976).

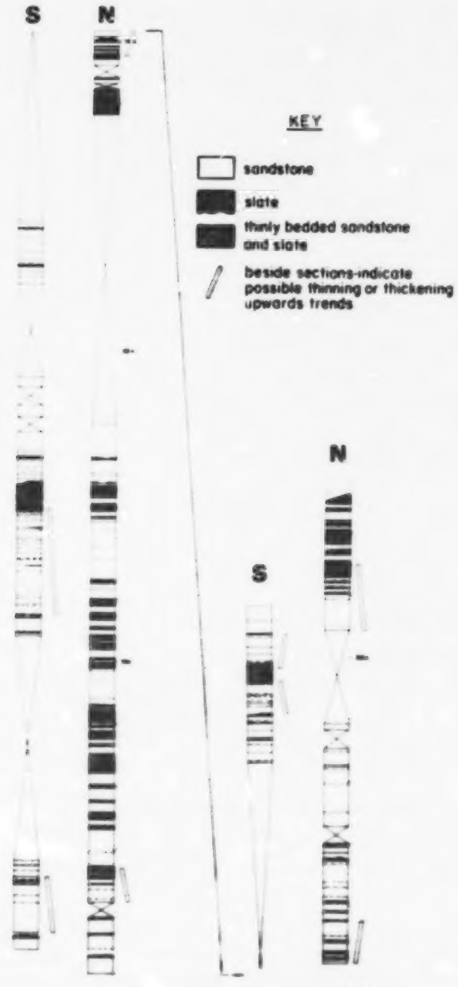
Beds with sharp upper surfaces do not correspond well with classical turbidites, but are believed to be modifications of types 1-3 above. Two processes were probably responsible for this modification (Fig. 2):

a) **Dewatering.** Water escaped from rapidly deposited sands, transporting grains upwards through the layers, and sometimes depositing them in small sand volcanoes on the upper surface. Graded silt and mud were deposited from suspension above this surface. This silt and mud probably represent the finer material suspended during dewatering as well as the waning stages of deposition from the turbidity currents.

b) **Reworking by bottom currents** may have produced sharp, rippled top surfaces overlain by slates containing isolated starved ripples and discontinuous laminae of sand and silt. Tectonic deformation of the commonly linguoid ripples generally precludes measurement of the current direction.

Occasional very thin (2-5 cm) beds of rather well sorted cross-laminated medium to coarse sandstone cannot be explained by either process, but appear similar to "facies E" of Mutti and Ricci Lucchi (1972). They are believed to represent overbank or mouthbar deposits associated with submarine-fan channels.

Direct observation of the geometry of sandstone bodies in the Goldenville Formation is not generally possible because of the difficulty of correlating along strike between sections. Current directions have low plunge, so that channels, if present, are unlikely to show up in the outcrop pattern. Correlation across an anticline at Indian Harbour (Fig. 3)


S
N
KEY
sandstone
slate
thinly bedded sandstone and slate
beside sections-indicate possible thinning or thickening upwards trends
N
S

Northern section after Smith (1981)

Figure 3. Sequences on northern and southern limbs of Wine Harbour Anticline. Note the probable correlation at the base and also around 75 m. Unexposed intervals prevent any attempt at correlation higher in the section. The actual distance between the sections increases upsection. Location: Indian Harbour.

suggests that considerable lateral variation occurs both in the overall thickness of packets of amalgamated type 1 sandstones, and in the proportion of sandstone which they contain. Thinning- and fining-upwards megasequences can be identified in some sections (Fig. 3); such megasequences are believed to be characteristic of channel-fills (Ricci Lucchi, 1975). However, while thinning upwards megasequences seem more common in Figure 2 than thickening-upwards trends, their identification is a subjective process, and considerable thicknesses of the Goldenville Formation show no discernable patterns. Further indications of channelling include:

i) lenticular and crosscutting relationships at erosive bases of massive sandstones

ii) abundance of intraclasts (over 50% by volume) at some horizons

iii) presence of "facies B" sand layers (see above) which supposedly represent overbank or mouthbar deposits.

Some horizons within the Goldenville Formation are associated with strong magnetic anomalies (Fig. 4). The origin of the anomalies is not yet fully understood, but is hoped that lateral correlation of horizons using magnetic profiles will lead to an improved definition of lateral facies changes in the Goldenville Formation and hence a better understanding of the depositional system.

Petrographic study of the sandstones is at an early stage. The sandstones are "sublitharenites" in the terminology of Folk (1974), but contain abundant metamorphic chlorite probably representing original clay matrix. Detrital components include quartz, alkali and plagioclase feldspars, muscovite, tourmaline, zircon, sphene, epidote, rock fragments and opaques. Some sandstones show a strongly bimodal grain-size distribution, with coarse to very coarse "millet-seed" grains of quartz, polycrystalline quartz, and sedimentary rock fragments dispersed in finer grained poorly sorted sand. They do not resemble the bimodal desert sands described by Folk (1968), in which both modes are supermature. The bimodality of these Goldenville Formation sandstones must therefore be the result of mixing of sands from at least two source areas. The locations of these source areas are at present unknown.

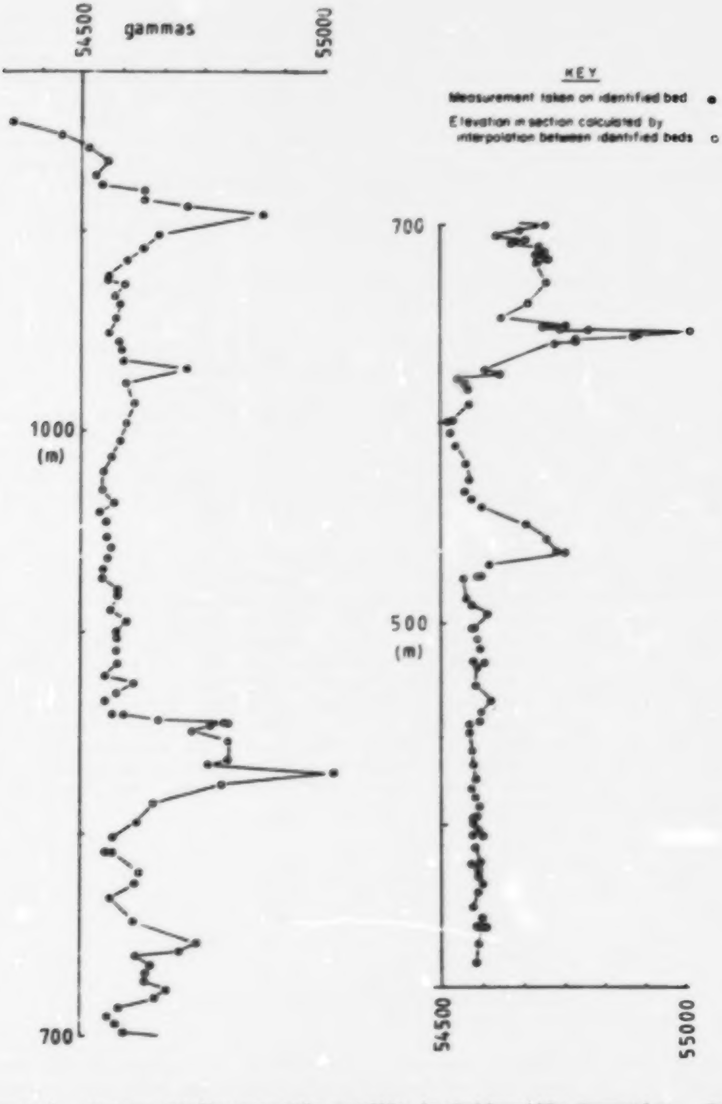


Figure 4. Across strike magnetic profile in Goldenville Formation. Total field plotted against stratigraphic height in Indian Harbour section (from Smith, in preparation). Magnetometer carried approximately 1.5 m above rock surface. The sharp magnetic anomalies appear to be associated with thick sandstone packets.

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ANALYSIS OF STRUCTURE AS A FACTOR CONTROLLING GOLD MINERALIZATION IN NOVA SCOTIA*

J. R. Henderson**

ABSTRACT

Quartz veins in the Goldenville Formation comprise three principal varieties: bedding-parallel (BP), en echelon (EE), and AC veins. The BP and EE veins are contemporaneous and lie in slate beds. They formed early in the strain history of folding at the time of formation of continuous and spaced cleavage during greenschist metamorphism. The AC veins formed in metawacke beds perpendicular to the fold axes late in the folding history.

The BP and EE veins are ubiquitous, but are auriferous only in gold districts in the region. The BP veins are not restricted to fold hinge regions and cannot be considered as saddle reefs. Vein fabrics and theoretical considerations support the view that all of the veins are due to hydraulic fracturing and that the fluids producing the fractures were derived locally.

RÉSUMÉ

Les filons de quartz de la formation de Goldenville se classent en trois catégories principales: filons BP parallèles à la stratification, filons EE en échelon et filons AC. Les filons BP et EE sont contemporains et sont trouvés dans des couches d'ardoise. Ils ont été formés au début de la phase de déformation du plissement, lors de la formation d'un clivage continu et espacé au cours du métamorphisme qui a conduit aux schistes verts. Les filons AC se sont formés dans des couches de métawackes perpendiculaires aux axes des plis, tard dans l'histoire du plissement.

Les filons BP et EE sont ubiquistes, mais ne contiennent de l'or que dans les zones aurifères de la région. Les filons BP ne sont pas limités aux charnières des plis et ne peuvent pas être considérés comme étant des voûtes anticlinales. L'étude des structures et des textures des filons ainsi que des considérations théoriques laissent supposer que tous les filons ont été formés par fracturation hydraulique et que les fluides ayant produit les fractures auraient été dérivés localement.

INTRODUCTION

The major objective of this study is to investigate the distribution and origin of gold-bearing quartz veins in part of the Cambro-Ordovician Meguma Group in eastern Nova Scotia. The study area

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Contribution to Canada-Nova Scotia Co-operative Mineral Program 1981-84. Project carried by Geological Survey of Canada.

**Geological Survey of Canada, Ottawa, Ontario

(Ecum Secum, Fig. 1) lies between 62°00' and 62°30'W., and extends from the Atlantic coastal islands north to the West River-St. Marys Fault. The area was chosen for study because of its relatively good bedrock exposure and relatively high concentration of gold mines and prospects. The Meguma Terrane east of the Ecum Secum area is currently under investigation by the Nova Scotia Department of Mines and Energy. The part of the study area around Ecum Secum (Fig. 2) was mapped in 1982 (this report); in 1983 we plan to extend the mapping north to the West River-St. Marys Fault, and integrate our mapping with the mapping being done to the east.

E. R. Faribault (1893, 1895a, 1896, 1897a, b) mapped the region around Ecum Secum (Fig. 2) at 1:63 360 scale, and published detailed maps and sections of Salmon River Gold District (1897c) at 1:3000 scale and Harrigan Cove Gold District (1906) at 1:4800 scale.

ACKNOWLEDGMENTS

I am grateful for mapping assistance from Frank Fueten, Jerry Naski, Steve McCollough, Dale Rafuse, Richard Stern, Claudia Stumpp, John Freeland, and Mariette Henderson. I appreciate discussions on Meguma gold deposits with Marcos Zentilli, Ulrich Kretschmar, Craig Miller, Simon Haynes, Duncan Keppie, Brian O'Brien and Paul Smith. I thank Simon Hanmer for reviewing the manuscript.

REGIONAL GEOLOGY

The Cambro-Ordovician Meguma Group comprises a lower sandy flysch (Goldenville Formation) and an upper shaly flysch (Halifax Formation). The auriferous quartz veins occur mainly in the Goldenville Formation. The contact between the formations in the Ecum Secum area is conformable and sharp (the contact is not drawn on the structural map, Fig. 2). Neither the top of the Halifax nor the base of the Goldenville Formations are exposed in eastern Nova Scotia.

The major fold axial surface traces in Meguma beds curve through a 90 degree arc from the southwestern coast of Nova Scotia to the region east of Ecum Secum (Fig. 1). In the Ecum Secum area (Fig. 2) the axial traces can be seen to consist of 2-10 km long segments that commonly are offset along their strike in a nonoverlapping, en echelon fashion (e.g. Southern Anticline and Sober Island Syncline). The offset is partly due to northwest-striking sinistral faults (e.g. Sheet Harbour Fault), but may be a primary feature elsewhere (e.g. south of Harrigan Cove and Ecum Secum mines). Note, however, that a 5 km long segment of the Gegogan Harbour Anticline's axial trace south of the Miller Lake mines shows dextral offset east of Liscomb River and sinistral offset near Ecum Secum River. Other folds in the area can be seen to terminate in an abrupt periclinal fashion where conical anticlinal and synclinal axial traces link (e.g. where the Wine Harbour Anticline links with the Sonora Syncline, and where the Salmon River Anticline links with the Ruth Falls Syncline). Within the Ecum Secum area fold limbs are approximately planar and dip 60-70 degrees, fold hinge areas are round to sharp, and axial surfaces are subvertical. The major folds antedate the intrusion of Devonian to Carboniferous granites into Meguma rocks outside of the map area (Fig. 1). The regional metamorphism

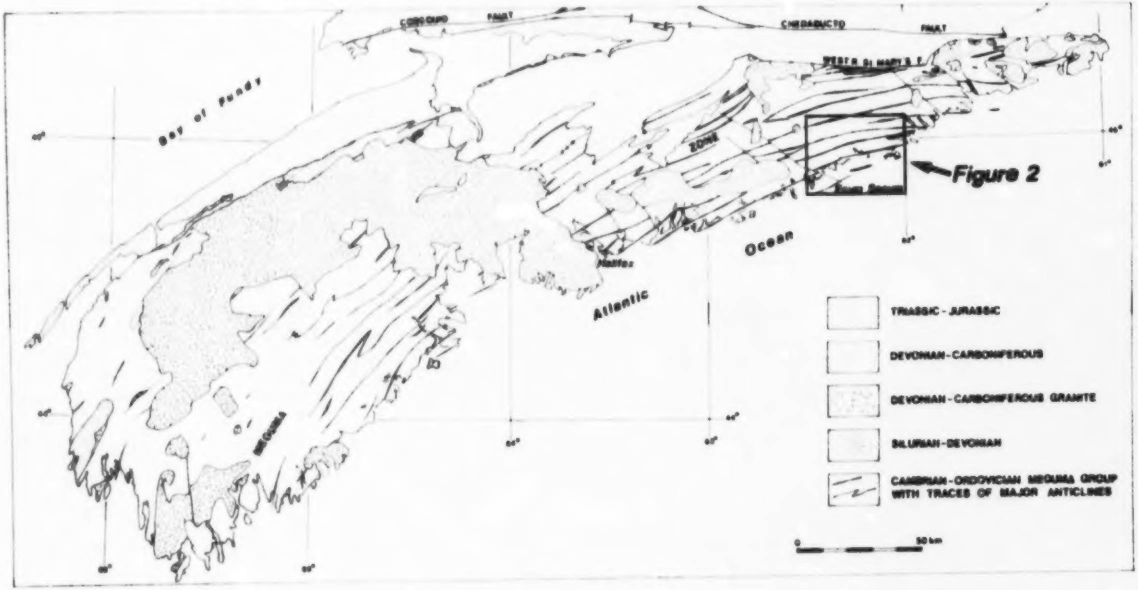
COBEQUID
FAULT
CHEDABUCTO
FAULT
Bay of Fundy
ZONE
Figure 2
Ecum Secum
Halifax
Atlantic
Ocean
MEGUMA
TRIASSIC - JURASSIC
DEVONIAN - CARBONIFEROUS
DEVONIAN - CARBONIFEROUS GRANITE
SILURIAN - DEVONIAN
CAMBRIAN - ORDOVICIAN MEGUMA GROUP WITH TRACES OF MAJOR ANTICLINES
0
50 km

Figure 1. General geological map of southern Nova Scotia showing location of the study area (Ecum Secum).

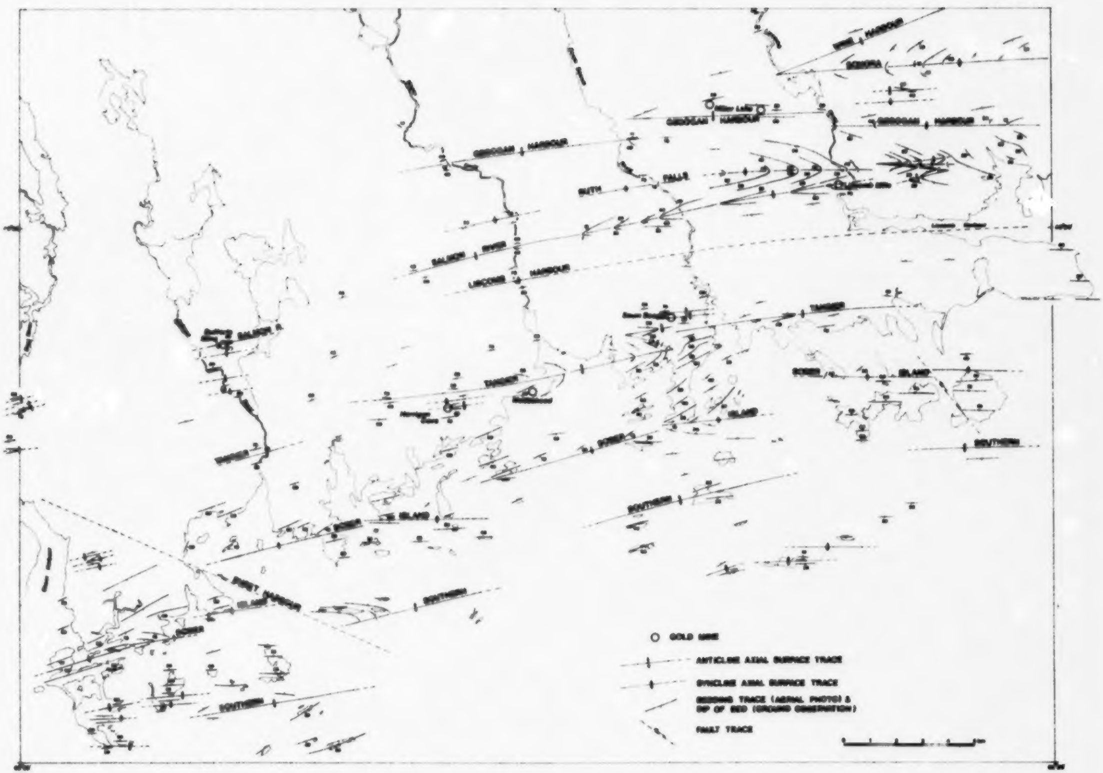
GOLD MINE
ANTICLINE AXIAL SURFACE TRACE
SYNCLINE AXIAL SURFACE TRACE
BEDDING TRACE (AERIAL PHOTO) & DIP OF BED (GROUND OBSERVATION)
FAULT TRACE

Figure 2. Structural map of the Ecum Secum area.

increases northward from chlorite grade in the area of Figure 2 to staurolite grade several kilometres south of the West River-St. Marys Fault.

REVIEW OF PREVIOUS WORK

Since the discovery in 1860 of auriferous gold veins in slates and arenaceous metawackes of the Meguma Group, numerous authorities have devoted considerable effort to predict the distribution of the deposits and explain their origin. Rickard (1912) provided an annotated bibliography of the important contributions on the subject published from 1862 to 1912; Malcolm (1928) listed a bibliography to 1928, Cameron (1947) provided a bibliography on Nova Scotia gold districts to 1947, and Graves and Zentilli (1982) presented a recent review of the geology of Nova Scotia gold deposits.

According to Faribault (1899) nearly all the rich veins and large bodies of quartz worked for gold in Nova Scotia parallel the bedding planes, and occur at well defined points along anticlinal crests, the centre of an elliptical dome being one of the most favourable places for the occurrence of quartz veins. From the analogy with the gold-bearing saddle reefs of Bendigo, Australia, operated profitably to depths greater than 1200 m, Faribault (1903) argued that in Nova Scotia saddle veins as large and rich in gold as those cropping out at the surface should occur at depth. In order to explain the localization of the veins, Faribault (1899) proposed that slip between thick, competent wacke beds caused fissures to open on the fold limbs along which quartz was deposited ("leg veins"). For anticlines with limbs dipping more than 70 degrees, large bodies of quartz were deposited in openings between the beds at the fold crests ("saddle veins" or "reefs"). He held further that mineralizing solutions were derived locally and that the folding and veining occurred slowly and intermittently. He observed that the quartz in the veins commonly contains minute scales of slate which had been peeled off the walls and subsequently covered by other layers of quartz, giving a laminated structure to the veins. Most of the gold occurs in streaks parallel with the laminations (Faribault, 1899). As early as 1864, Benjamin Silliman Jr., proposed a contemporaneous origin for the veins and folds, and Dawson (1868) noted that the auriferous bedding-parallel quartz veins definitely were not beds, as evident from the way veins branched off into the neighbouring rocks.

Keppie (1976) re-evaluated the anticlinal saddle reef hypothesis of Faribault, and concluded on the basis of a modified concentric fold model that the size of saddle reef veins should increase with the fold tightness (Keppie's "Curvature Index"), and in anticlines of the Goldenville Formation the Curvature Index indicates that saddle reef size should increase with depth.

Recently, Graves and Zentilli (1982) argued on the basis of composition, texture and geometry that the vein minerals were precipitated rapidly from an aqueous fluid which generated hydraulic fractures during greenschist metamorphism. They assumed that the least tectonic stress was vertical at the onset of horizontal compression, and horizontal, bedding-parallel hydraulic fractures formed when the fluid pressure exceeded the least tectonic stress. The sequence of events proposed by

Graves and Zentilli (1982) is 1) vein formation, 2) folding, and 3) cleavage development. Faribault and Keppie directly linked the vein formation and the folding process, whereas Graves and Zentilli believed that the veins antedate the folds and that in some places tight folding of the auriferous quartz veins has produced a mechanical enrichment, presumably by increasing the vein length per chord length of major structures in the fold profile plane.

BEDDING-CLEAVAGE RELATIONS IN THE ECUM SECUM AREA

Arenaceous metawacke and slate, the principal lithologies of the Meguma Group, exhibit continuous (i.e. slaty, penetrative) cleavage in the Ecum Secum area. In addition, arenaceous metawacke exhibits spaced cleavage parallel to the continuous cleavage. In slates continuous cleavage is defined by parallel alignment of chlorite flakes, and in metawacke continuous cleavage is defined by the planar preferred shape fabric of detrital quartz and feldspar grains as well as parallel alignment of secondary quartz, chlorite and sericite which form "beards" attached to detrital sand grains (Fig. 3). Spaced cleavage appears as phyllosilicate-rich seams. The seams vary in width up to several centimetres (Fig. 4) and become more closely spaced in the hinge regions of folds. The continuous and spaced cleavages in metawacke beds are parallel in the Ecum Secum area.

Figure 5 shows typical bedding-cleavage geometries in interbedded metawacke and slate. The bedding surface dipping to the left at 30 degrees shows rounded profiles of sand volcanoes capping dewatering sheets or pipes in the upper part of a metawacke bed. The dewatering structures are penecontemporaneous features formed by the rapid expulsion of water from a "quick" bed, and elutriation of coarse sand upward from the base of a turbidite (Dzulynski and Walton, 1965). The spaced cleavage in the wacke bed, shown by the thin dark stripes, is parallel to the light water-escape structures and dips in the direction opposite to the bedding. The dark slate overlying the metawacke exhibits continuous cleavage dipping more steeply, but in the same direction as the bedding. In Figure 5 the two cleavages show an abrupt refraction across the wacke/slate contact; in graded beds on fold limbs the refraction is gradual. In the troughs and crests of folds, cleavages in metawacke and slate are normal to subhorizontal bedding surfaces (Fig. 4).

An upper surface of a metawacke bed covered with elliptical sand volcanoes is shown in Figure 6. The truncated sand volcanoes exhibit radial, concentric or homogeneous interiors with a small central vent (Figs. 7, 8). Their maximum elongation is everywhere parallel to the cleavage trace on the bedding surface. On a few bedding surfaces the elliptical structures are aligned en echelon parallel to traces of dewatering sheets, but most commonly the sand volcanoes occur in swarms capping randomly distributed dewatering pipes (Fig. 6). A graph of sand volcano aspect ratio (length:width) vs. cumulative per cent frequency, measured on bedding surfaces dipping less than 30 degrees and more than 60 degrees, is shown in Figure 9. The two curves are not significantly different; both indicate a strong unimodal distribution at $X/Z=2$. The data may be interpreted to suggest that either the principel extension direction for the rocks is parallel to the fold axis and/or that the sand volcanoes were flattened in the cleavage plane when bedding was horizontal and

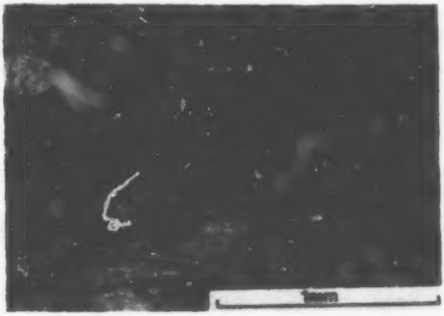

Figure 3. Photomicrograph of metawacke showing continuous cleavage defined by elliptical detrital quartz and feldspar grains, with secondary quartz-mica beards attached to the detrital grains. 2HSA-C22-AC

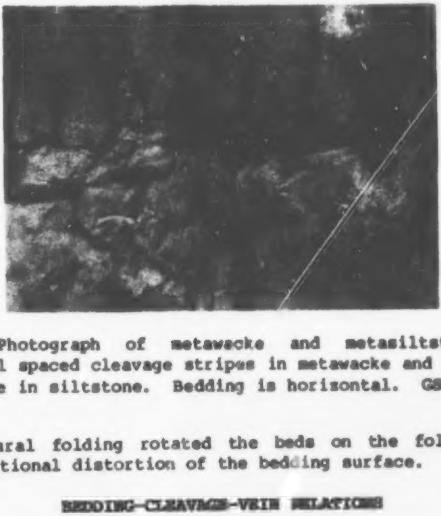

Figure 4. Photograph of metawacke and metasiltstone with vertical spaced cleavage stripes in metawacke and continuous cleavage in siltstone. Bedding is horizontal. GSC 1-20-82

subsequent flexural folding rotated the beds on the fold limbs without appreciable additional distortion of the bedding surface.

BEDDING-CLEAVAGE-VEIN RELATIONS

Quartz veins (commonly quartz-carbonate-chlorite) are ubiquitous throughout the Goldenville Formation in the map area. Auriferous quartz veins, however, have been found only in the areas of gold mines indicated in Figure 2. Exposure is poor in the gold districts, and much of the information on the nature of the auriferous veins must be obtained from the literature; observations on barren quartz veins, on the other hand, are useful to make comparisons with descriptions of auriferous veins made by previous workers.

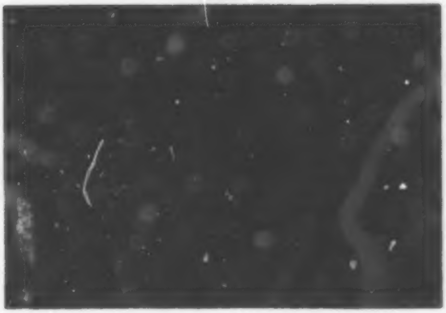

Figure 5. Photograph of metawacke below dark slate showing spaced cleavage stripes (dark) parallel to dewatering sheet traces (light colour with swelling towards top of bed) in metawacke. Note abrupt refraction of slaty cleavage across bedding trace. GSC 203539-H

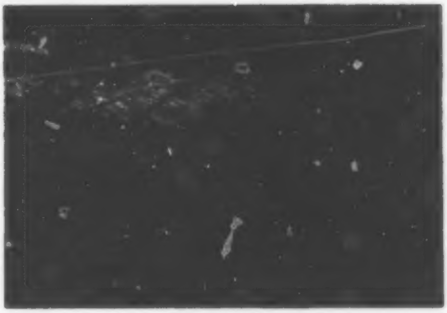

Figure 6. Photograph of an upper surface of a metawacke bed covered with elliptical sand volcanoes. Their maximum elongation is parallel to the spaced cleavage trace. GSC 203683-L

Figure 7. Photograph of a sand volcano on a bedding surface showing radial internal structure and a central vent. Differential erosion of the radial septae and vent probably are due to their higher content of detrital(?) carbonate grains. GSC 203539-M

Figure 8. Photograph of sand volcanoes on a horizontal bedding surface showing homogeneous interiors and central vents. GSC 203603-A

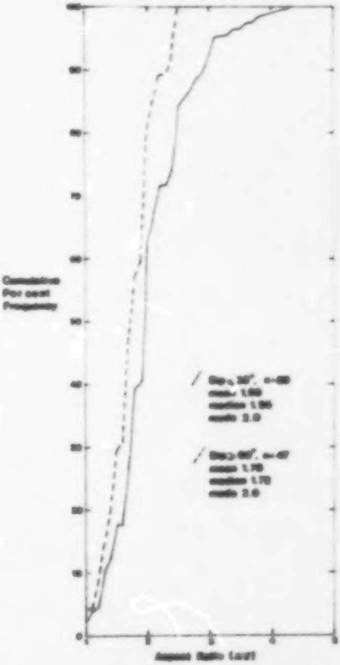

Figure 9. Graph showing sand volcano aspect ratios (X:Z) vs. cumulative per cent frequency measured on bedding surfaces dipping from 0-30°, and 60-90°.

On the basis of geometry I have distinguished three principal types of quartz veins within the Ecum Secum area: 1) veins lying parallel to bedding planes ("BP" veins), 2) veins lying within slate beds but terminating with short "hooks" extending into adjacent metawacke beds ("HS" veins), and 3) veins lying within metawacke beds in planes approximately normal to the local fold axis ("AC" veins).

Bedding-parallel veins most commonly occur near the top of a slate bed, and at the interface between slate and an overlying metawacke bed. The BP veins may contain several layers of quartz separated by thin laminae of slate, they may be made up of coarse, massive quartz, or they may consist of both layered and boundinaged massive quartz (Fig. 10). Commonly, veins with layered quartz also exhibit folded coarse quartz fibres aligned in the plane of the vein, approximately normal to the fold axis (Fig. 11). The fibrous quartz veins are found on the limbs and hinges of folds.

Figure 10. Photograph of a bedding-parallel quartz vein showing both layered fabric and massive quartz "rolls". Viewed parallel to the long axes of the rolls which parallel the local fold axis. GSC 203683-D

Figure 11. Photograph of a subhorizontal bedding-parallel quartz vein showing quartz extension fibres lying in the plane of the vein. The small fold axes are parallel to the local fold axis in bedding. GSC 203683-E

En echelon veins occur on the limbs of the large folds in the area. Their intersection with the bedding is subparallel to the fold axis (although one example of two EE veins intersecting bedding parallel to the dip line was seen). Figure 12 shows a typical EE quartz vein viewed parallel to its horizontal intersection with bedding. The vein in the figure consists of a two-metre long nearly vertical segment crossing a metre-wide slate bed, and with sharply bent, hook-like terminations in the adjacent metawacke beds. Several other EE quartz veins occur in the same slate bed slightly above and below the vein in the photograph.

In contrast to the BP and EE veins the AC veins are confined to metawacke beds. Quartz veins of this class occur both in limb and hinge areas of folds. Commonly the AC veins occur in single fractures filled with quartz crystals; they also occur as conjugate sets of short en echelon veins that form an acute intersection with the AC plane beyond the termination of a single AC vein. They postdate the folding and record a small amount of east-west extension parallel to the fold axes. The AC veins are deformed by conjugate sets of kink bands in spaced cleavage. The conjugate kink bands record a small amount of east-west shortening (Fig. 13).

Interpretation of Bedding-Cleavage-Vein Relations

Figure 14 summarizes the geometric features of the principal veins, cleavages and folds in the Ecum Secum area. Parallelism of water escape structures and spaced cleavage on fold limbs, as well as identical aspect ratios of sand volcanoes on fold hinge and limb regions, indicate that: (1) bedding and cleavage were originally perpendicular, and (2) the cleavage refraction is due to different distortions in metawacke and slate beds during flexural-shear folding.

The BP and EE veins are auriferous and are contemporaneous in the gold districts; they are older than the AC veins, which are barren. For example, Hedley (1941) and Bell (1948) described contemporaneous BP veins ("leads") and EE veins ("angulars") in the Goldenville and Caribou districts that were particularly auriferous where the two types of veins intersected.

Figure 15a represents the bedding-cleavage-vein geometry of EE veins shown in Figure 12. The slaty cleavage trace lies in the acute angle between bedding and the EE quartz veins. If the veins as seen now originally formed as en echelon tension gashes at the onset of folding, the geometry shown in Figure 15b is obtained by removing a dextral shear strain of 2.75 parallel to the bedding in the slate. This restores the EE vein in Figure 15a to an original 45° angle, and also restores the slaty cleavage to a 90° angle with bedding.

The BP veins with parallel lamination and quartz fibre lineation (Figs. 10, 11) resemble veins described by Ramsay and Huber (in press) as either shear fibre veins or stretched crystal veins wherein the lineations parallel the incremental stretching directions. Given that: (a) the crystal fibres in the BP veins observed in the Ecum Secum area are aligned in the plane of the veins, perpendicular to the fold axis, and b) that the veins occur in both limb and hinge zones of folds, the BP veins could antedate the folds or have formed early in the strain history of folding.

Figure 12. Photograph showing an en echelon quartz vein crosscutting a dark slate bed and terminating with short "hooks" in the bounding metawacke beds (arrows point to hooks). View east parallel to the line of intersection of the vein and bedding. GSC 203539-I

Figure 13. Photograph showing an AC quartz vein. The vertical vein is normal to the spaced cleavage in the horizontal metawacke bed and is offset slightly by a right-hand kink band in the spaced cleavage. Note also the conjugate left-hand kink band. The pen lies parallel to the extension direction (E-W) for the vein and the compression direction for the kink bands. GSC 203683-6

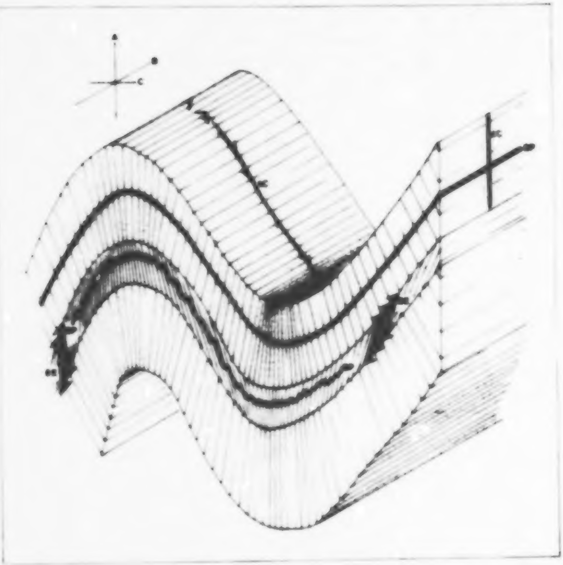

Figure 14. Sketch showing the relationships of the principal veins to folds and cleavages in the Ecum Secum area. Metawacke beds are stippled, slate is in centre and veins are black.

There are two possible mechanisms: (1) formation of shear fibre veins during prefold layer-parallel slip, or (2) modification of hydraulic fracture-fill by layer-parallel slip. It is not yet feasible to unequivocally distinguish between these two possibilities.

Some constraints can be applied: (a) shear fibre vein formation prior to folding can only imply minor layer-parallel slip since removal of the bedding-parallel shear component due to folding restores cleavage to its layer normal position and the EE veins to their initial 45° position, (b) shear fibre vein formation during folding implies major hinge migration, for which there is no evidence, in order to account for BP vein development in the hinge regions of large wavelength folds, and (c) formation of hydraulic BP extension veins could occur either during or prior to folding.

The persistence of the fibre lineation in the fold hinge zones implies that modification of such veins by layer-parallel slip during folding must be accompanied by at least a minor amount of hinge migration. Such hinge migration may only subtly modify the prefold cleavage, and may not be detectable from our field data.

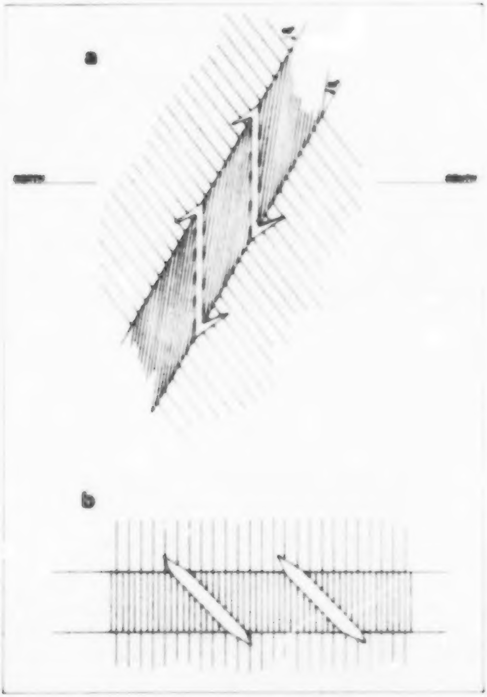

Figure 15. Geometry and origin of en echelon quartz veins.
a. Present geometry of en echelon veins, bedding and cleavage in metawacke (stipple) and slate (close-spaced cleavage traces).
b. Apparent original geometry of en echelon veins as en echelon tension gashes in slate formed prior to the major folding.

The local contemporaneity of BP and EE veins, and constraint (a) above suggest that BP veins either formed during the final prefolding strain increment or very early during folding. In either case, BP veins do not correspond to saddle-reef structures.

Support for a hydraulic fracture-fill origin of BP veins is given by the EE veins. Formation of the EE veins as brittle tension-gash features is not associated with significant ductile deformation within the slate units where they occur, and implies that the slates were more brittle than the metawacke beds. These observations may be accounted for by localised high pore fluid pressures within the slate units, which by reducing the effective normal stress term in the modified Coulomb failure criterion (e.g. see Hobbs et al., 1976) would enhance brittle behaviour in the slate. Price (Fyfe et al., 1978) has shown that onset of flexural folding is also enhanced by high pore fluid pressures, and that shearing resistance on bedding surfaces can be reduced to a few tens of bars at more than 10 km depth. At these depths temperatures of around 300°C would be expected to occur, and fluids generated during metamorphic reactions could account for the high pore pressures (e.g. Graves and Zentilli, 1982).

The AC veins are consistent with the hydraulic extension fracture hypothesis also, and indicate that at their stage in the strain history the least tectonic stress was approximately horizontal east-west when the effective normal stress exceeded the tensile strength in metawacke beds.

In order for hydraulic fracturing to occur rocks must lack permeability, and therefore the solutions from which the vein minerals precipitated must be locally derived from slate and/or metawacke.

Table 1 summarises the salient features of the principal vein types in terms of their geometry, fabric, relative age and mineralisation potential. In the Ecum Secum area BP and EE veins formed in brittle slate contemporaneously with the cleavage development, and were succeeded by the folding. The AC veins developed in brittle metawacke at a later stage in the deformation when the least tectonic stress was parallel to the fold axes. The conjugate kink bands in spaced cleavage postdate the AC veins in metawacke, and formed when the maximum tectonic stress was parallel to the fold axes. Perhaps the northwest-striking sinistral faults formed under the stress conditions that produced the kink bands.

Table 1. Classification of principal veins in the Ecum Secum area

CLASS	GEOMETRY	FABRIC	RELATIVE AGE AND MINERALIZATION POTENTIAL
BP	1. Bedding-parallel, cm-wide veins in slate, commonly folded on much shorter wavelengths than the folds in metawacke beds.	Quartz and chlorite laminae with quartz extension fibres sub-parallel to the vein walls.	Form early in history of folding, commonly auriferous in gold districts
	2. Decimetre-wide metawacke beds, folded on same wavelength as bedding in metawacke.	Massive quartz with no apparent preferred growth habit.	Form early in history of folding, auriferous in gold districts, distinguished from fibre veins on basis of fabric.
EE	En echelon arrays of veins in slate beds that are discordant to bedding and cleavage and terminate with short hooks in adjacent metawacke beds. EE veins most commonly intersect bedding parallel to the local fold axis.	Massive quartz and chlorite with no preferred growth habit.	Form in extension fractures early in history of folding and after cleavage formation, their present geometry is due to bedding-parallel shear during folding. Auriferous in gold districts.
AC	Centimetre-wide veins in planes normal to fold axes in metawacke beds.	Quartz crystals normal to vein walls, also massive quartz.	Postdate BP and EE veins, record a period of extension parallel to fold axes. Barren veins in gold districts.

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OBSERVATIONS ON THE NATURE AND ORIGIN OF MAGNETIC TOTAL FIELD AND VERTICAL GRADIENT ANOMALIES OVER THE GOLDENVILLE FORMATION IN NOVA SCOTIA*

Richard A. Stern ** and J. R. Henderson***

ABSTRACT

Fluctuations in magnetite content of metaturbidites in the Goldenville Formation produce total magnetic field and vertical magnetic gradient anomalies that are detectable with a portable magnetic gradiometer. A ground magnetic survey carried out over bedrock as well as till-covered bedrock shows that some magnetic anomalies in the total field and vertical gradient are sufficiently characteristic to permit correlations to be made from profile-to-profile across the 6 km width of the study area. Matching anomalies in overlapping parts of adjacent profiles enabled the construction of a composite magnetic and lithological section of 2.3 km in total. Magnetite is the only strongly magnetic mineral detected, and is found in some sandy metawacke beds in amounts of less than one weight per cent. Slate beds as well as some metawacke beds do not contain magnetic phases. Detailed analysis of the magnetism in the Goldenville Formation may be useful for stratigraphic subdivision of the monotonous metaturbidites, lithofacies analysis, and provenance studies.

RÉSUMÉ

Les fluctuations du contenu en magnétite des métaturbidites de la formation de Goldenville produisent des anomalies du champ magnétique total et du gradient magnétique vertical qui peuvent être détectées par un gradiomètre magnétique portatif. Un relevé magnétique au sol, mené à bien au-dessus d'affleurement ainsi qu'au-dessus de zones couvertes de till, démontre que certaines anomalies du champ total et du gradient vertical sont suffisamment caractéristiques pour permettre la corrélation de profil à profil sur une largeur de 6 km de la région étudiée. Une section magnétique et lithologique composée d'une épaisseur totale de 2,3 km a été construite en faisant correspondre les anomalies de parties chevauchantes de profils voisins. La magnétite est le seul minéral fortement magnétique détecté et on en trouve moins de un pourcent en poids dans certains lits de métagrauwacke arénacée. Les lits de schiste et certains lits de grauwacke ne contiennent pas de phases magnétiques.

L'analyse détaillée du magnétisme de la formation de Goldenville peut être utile pour la subdivision stratigraphique des métaturbidites monotones, l'analyse du lithofaciès et les études de provenance.

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INTRODUCTION

Recent aeromagnetic total field and vertical gradient surveys of parts of Nova Scotia (Geological Survey of Canada, 1982a,b) indicate the presence of linear magnetic anomalies over the Goldenville Formation of the Meguma Group. Some of these magnetic anomalies are several hundreds of metres wide and extend for more than 30 km parallel to the strike of bedding. They indicate that characteristic magnetic horizons may be used to subdivide the Goldenville Formation. In May 1982 a two-year program was begun to map the Meguma Group in the Ecum Secum-Liscomb area of Nova Scotia (Henderson, 1983) from the Atlantic coast to the West River-St. Marys Fault between 62°00'W and 62°30'W (Fig. 1). An aeromagnetic total field and vertical gradient survey was flown over the map area in September 1982 by the Geological Survey of Canada. In order to evaluate the forthcoming aeromagnetic data, a program of ground magnetic profiling was carried out using a portable magnetic gradiometer. The principal objectives were: (1) to determine the cause of the aeromagnetic responses over the Goldenville Formation, and (2) to determine whether the portable gradiometer could be useful in defining and correlating marker beds by recognizing small magnetic features not resolved by an aeromagnetic survey.

The study area (Fig. 2) consists of Crooks, Goose, and Barren islands which were selected because of their abundant shoreline outcrop and relatively treeless, till-covered interiors. The area is entirely in the Goldenville Formation on the southern limb of the Sober Island Syncline where the beds dip north at 60 to 70 degrees (Fig. 2). The Goldenville Formation consists of chlorite grade sandy metawacke and slate composing a metaturbidite succession. The formation is estimated to be 5.6 km thick (Faribault, quoted *in* Taylor, 1967). In the late 19th and early 20th centuries more than 35 million grams of gold were recovered mainly from stratabound quartz veins in the Goldenville Formation (Graves and Zentilli, 1982).

ACKNOWLEDGEMENTS

We are grateful for the advice and support of Les Kornik throughout the study. Steve McCollough provided invaluable assistance in carrying out all aspects of magnetic and lithological data collection and machine profiling. We thank Ken Buchan, Peter McGrath, John B. Henderson and Les Kornik for reviewing the manuscript.

GRADIOMETER SURVEY

Nine ground magnetic profiles were made over the survey area to determine the magnetic character of a typical Goldenville sequence of rocks. Total magnetic field and vertical magnetic gradient measurements were taken at two-metre intervals along north-south lines using a one-man, portable gradiometer. For the purpose of comparison, the lines were run both across areas of good shoreline exposure and across mainly till-covered inland areas.

The measuring system consisted of an EDA PPM-500 Vertical Magnetic Gradiometer, an EDA PPM-400 Base Station Magnetometer to monitor diurnal variations in the magnetic field, and a Hewlett-Packard HP-85

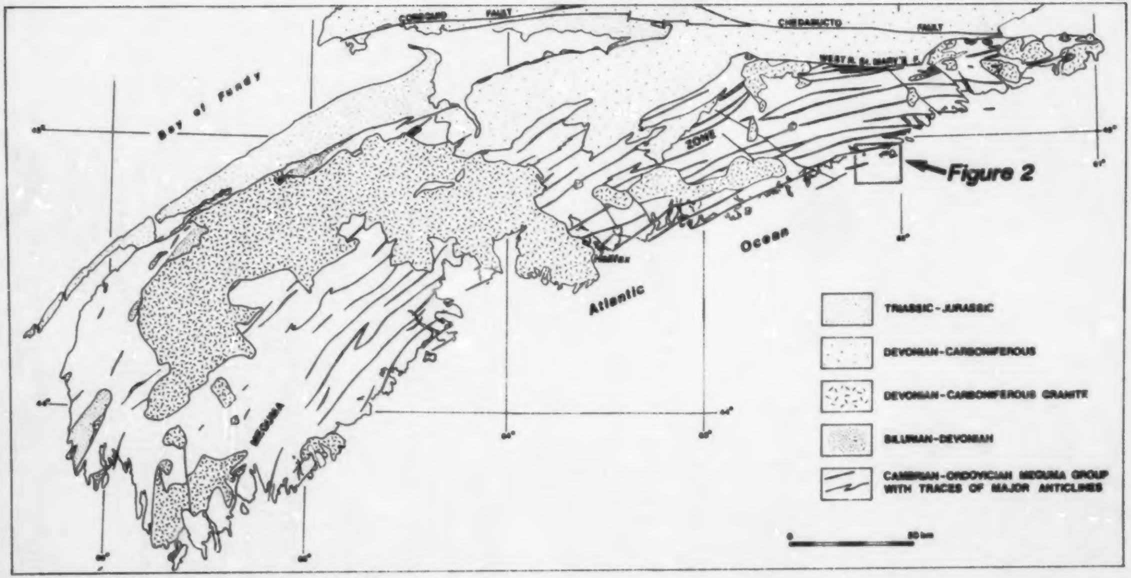

CONEQUID FAULT
CHEDABUCTO FAULT
WEST R. St. MARY'S F.
ZONE
Bay of Fundy
Atlantic
Ocean
Halifax
MEGUMA
Figure 2
TRIASSIC - JURASSIC
DEVONIAN - CARBONIFEROUS
DEVONIAN - CARBONIFEROUS GRANITE
SILURIAN - DEVONIAN
CAMBRIAN - ORDOVICIAN MEGUMA GROUP WITH TRACES OF MAJOR ANTICLINES
0
50 km

Figure 1. General geological map of southern Nova Scotia. The area shown in Figure 2 is outlined.

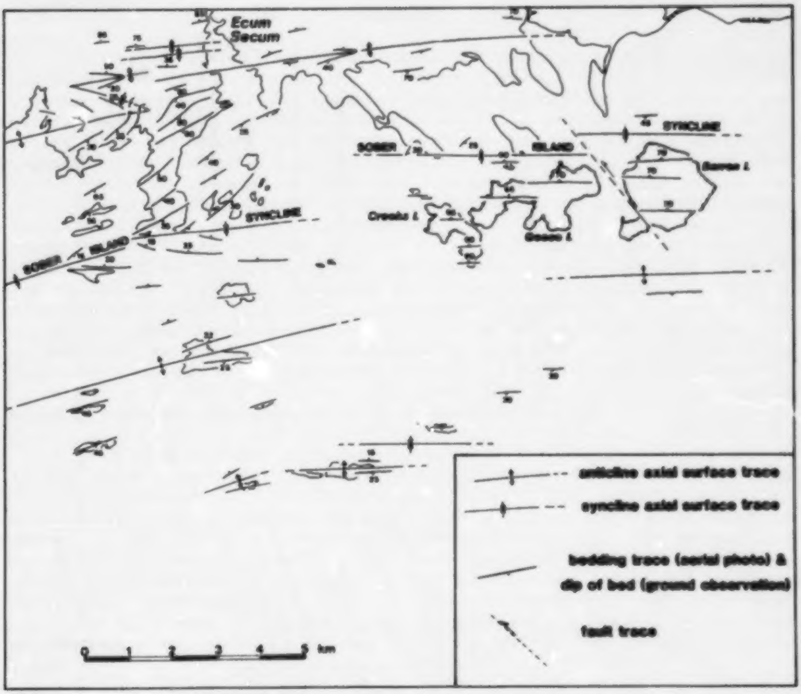

Ecum Secum
SYNCLINE
SOBER ISLAND
SYNCLINE
SOBER ISLAND
Crooks I.
Goose I.
Barren I.
SYNCLINE
anticline axial surface trace
syncline axial surface trace
bedding trace (aerial photo) & dip of bed (ground observation)
fault trace
0 1 2 3 4 5 km

Figure 2. Structural geological map of the area south of Ecum Secum showing the location of Crooks, Goose and Barren islands.

microcomputer for machine profiling of the magnetic data with a preprogrammed tape supplied by EDA Instruments, Inc.

The PPM-500 Vertical Magnetic Gradiometer (Fig. 3) has two total magnetic field sensors, located one metre apart on a vertically held pole. The sensors are simultaneously energized, and the difference in the total magnetic field between the upper and lower sensors divided by the sensor separation of one metre yields the vertical magnetic gradient in gammas per metre. The readings are retained in a built-in memory. The results of the vertical gradient survey are shown in Figure 4. The total magnetic field reading obtained from the upper sensor is retained as the total magnetic field value. The results of this survey are shown in Figure 5.

Results

The magnetic profiles (Figs. 4, 5) show that the Goldenville Formation has distinctive magnetic horizons that can be traced from profile-to-profile across the three islands. Profiles A, C, E, F, G and I are over coastal sections of excellent bedrock exposure; profiles B, D, and H are over till-covered inland areas with a few bedrock ridges of metawacke. The affect of thin till cover on the magnetic response of the beds appears to be negligible in the survey area. Dashed correlation lines in Figures 4 and 5 connect similar points between the profiles. This ability to correlate magnetically between profiles resulted in the identification of a 400 m sinistral offset of magnetic markers between profile lines F and G (Figs. 4 and 5). This is interpreted as offset across a fault near the western shore of Barren Island. Brecciated rocks occur along the strike of the inferred fault zone and support the interpretation.

Figure 3. The EDA PPM-500 Vertical Magnetic Gradiometer in operation over an outcrop of the Goldenville Formation on Goose Island. GSC 203683-V.

RELATIONSHIPS BETWEEN MAGNETICS AND LITHOLOGY

Stratigraphic sections of 2300 m combined thickness were measured in order to determine the relationship between the rocks and their magnetic signature. The total section was divided into five subsections, located across beach profiles A, C, E, G and I, that were also surveyed with the gradiometer (Figs. 4, 5). The beds were classified according to the classical Bouma (1962) turbidite sequence: massive, graded division A; plane parallel laminated division B; ripple bedded division C; upper parallel laminated division D; pelitic division E.

The relationships between magnetic response and lithology are illustrated in Figure 6 where a 170 m stratigraphic interval, present, at least in part, in all profiles, has been identified and correlated across the study area by matching magnetic vertical gradient and total field profiles. In Figure 6 the magnetic profiles over the 170 m interval have been superimposed for comparison. The corresponding parts of lithological subsections C, E, and G, are placed below the magnetic profiles so that the beds responsible for the magnetic variations can be indentified.

The following generalizations can be made about the magnetic characteristics of the Goldenville Formation with reference to Figure 6:

1. The total magnetic field values increase as the proportion and volume of Bouma A, B, and C divisions (metawacke) increase.

2. The contact of large metawacke units with slate (Bouma D and E divisions) commonly is marked by a change from negative magnetic gradients (slate) to positive gradients (metawacke); the metawacke-slate contact is close to the zero gradient crossover.

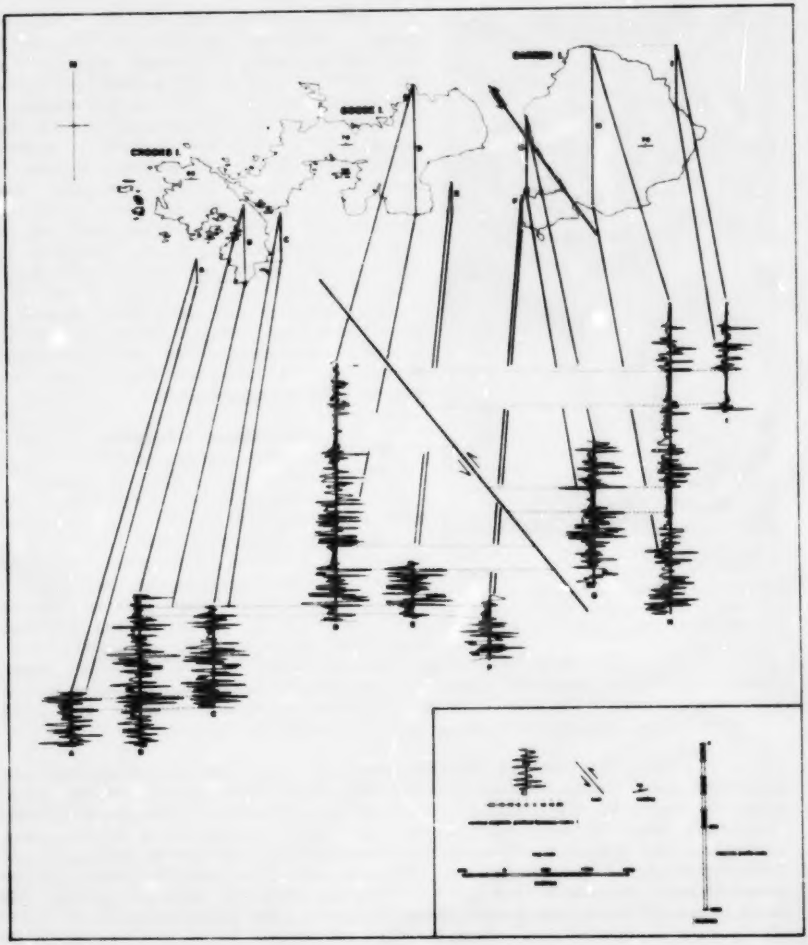


Figure 4. Correlation diagram showing vertical magnetic gradient profiles A-I and their location on the three islands. Profiles A, C, E, F, G, and I were run over shoreline outcrops and are projected onto north-south lines; the inland profiles B, D and H were run along north-south lines. Dashed lines connect correlative magnetic intervals between the profiles. Note the left-hand offset of the correlative intervals across an inferred fault between profiles F and G.

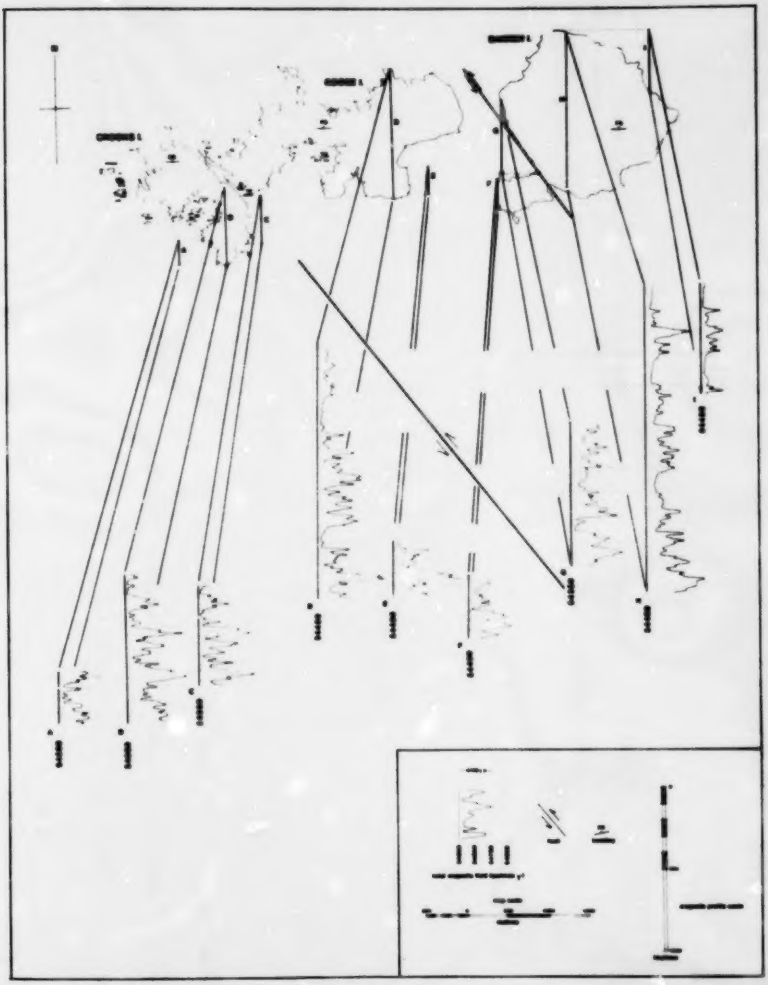
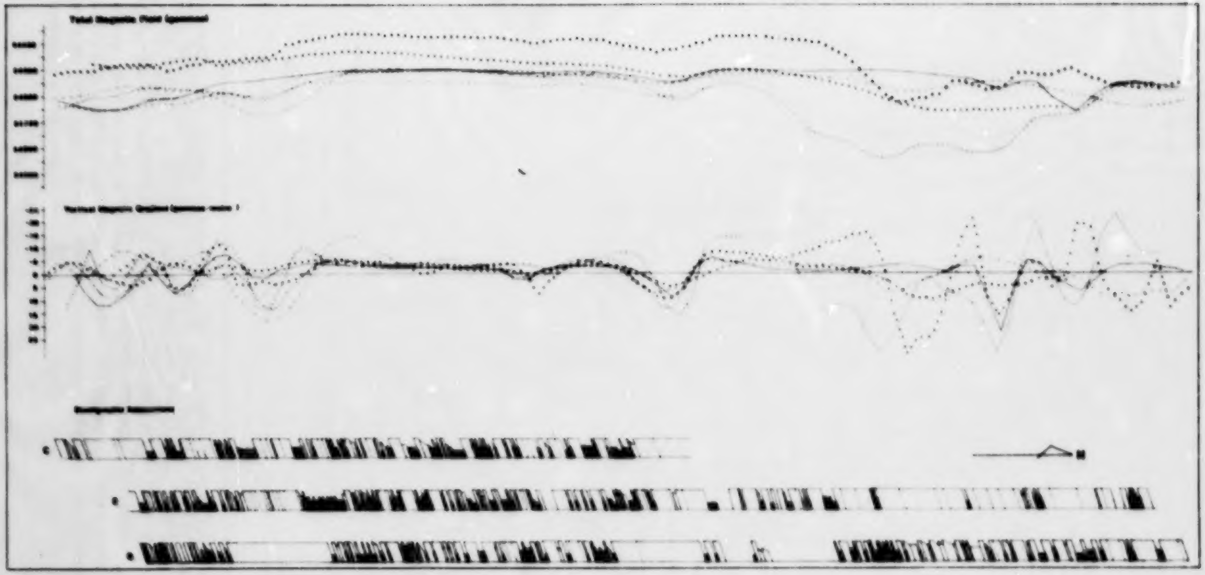


Figure 5. Correlation diagram showing total magnetic field profiles A-I and their locations on the three islands. Dashed tie lines connect correlative magnetic intervals between profiles, and are the same correlations as those of Figure 4.


Total Magnetic Field (gammas)
Vertical Magnetic Gradient (gammas meter-1)

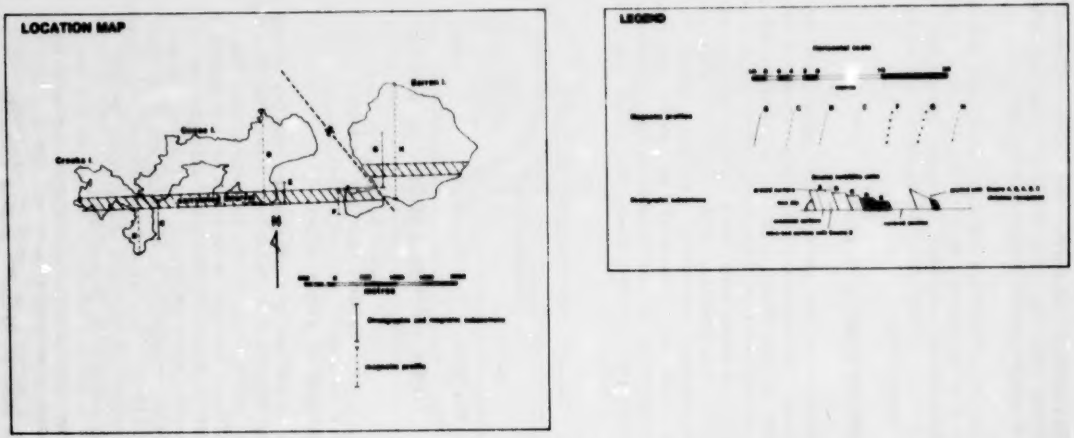


Figure 6. Magnetic correlation diagram showing a 170 m interval of the Goldenville Formation. Magnetic profiles B-H are overlapped for comparison. Note that positive gradient and total magnetic field values increase downward in the figure. Equivalent parts of stratigraphic subsections C, E and G are aligned below the profiles in order to compare the magnetic responses with the lithologies.

3. Some sequences of interbedded metawacke and slate possess smooth magnetic gradient profiles that lie near the zero gradient level, and the two lithologies are indistinguishable magnetically.

In summarizing the relationships between lithology and magnetic signature, it can be seen that metawacke very commonly shows high total magnetic field values and positive vertical gradient anomalies, whereas slate shows low total field values, and, where adjacent to metawacke, shows negative vertical gradient anomalies.

CAUSES OF MAGNETIC ANOMALIES

McGrath (1970) attributed the aeromagnetic anomalies associated with the Goldenville Formation to magnetite in sandy metawacke beds. In order to verify this finding in the study area and to investigate further the magnetic character of the Goldenville Formation, heavy mineral analyses and magnetic susceptibility measurements were performed on metawacke samples from three locations, representing high negative, high positive, and zero vertical magnetic gradient anomalies. Figure 7 shows the three sample sites, G-1, G-2, and I-1, located on their stratigraphic subsections. Beside each subsection the corresponding total magnetic field and vertical magnetic gradient profiles are drawn. The results of the heavy mineral analyses are shown in Table 1.

Table 1. Heavy mineral analyses

Heavy Minerals[2]	Sample Sites[1]		
	G-1	G-2	I-1
magnetite[3]	0.2 wt.%	0.8 wt.%	trace
hematite[4]	trace amounts as alteration of magnetite		
other[5]	0.1 - 0.2 wt.% epidote>>titanite>zircon		

[1] See Figure 7 for location of sample sites.

[2] Heavy minerals were extracted by crushing and sieving of the samples, followed by immersion in bromoform (specific gravity 2.85) and methylene iodide (s.g. 3.32) to concentrate the heavy mineral fraction. Further separation of the minerals was done on the basis of magnetic character with the use of a hand magnet and a Frantz electromagnetic separator. Mineral identification under the binocular microscope was confirmed by X-ray diffraction analysis. All size fractions of the crushed rock were analyzed magnetically, thus the mineral weight percentages are true whole-rock percentages.

[3] Magnetite (Fe_3O_4) was removed with hand magnet and with the Frantz magnetic separator set at 0.1A.

[4] Hematite (Fe_2O_3) was removed with the Frantz magnetic separator set at 0.25A.

[5] Fraction of the sample that was not removed with the Frantz magnetic separator set at 0.25A.

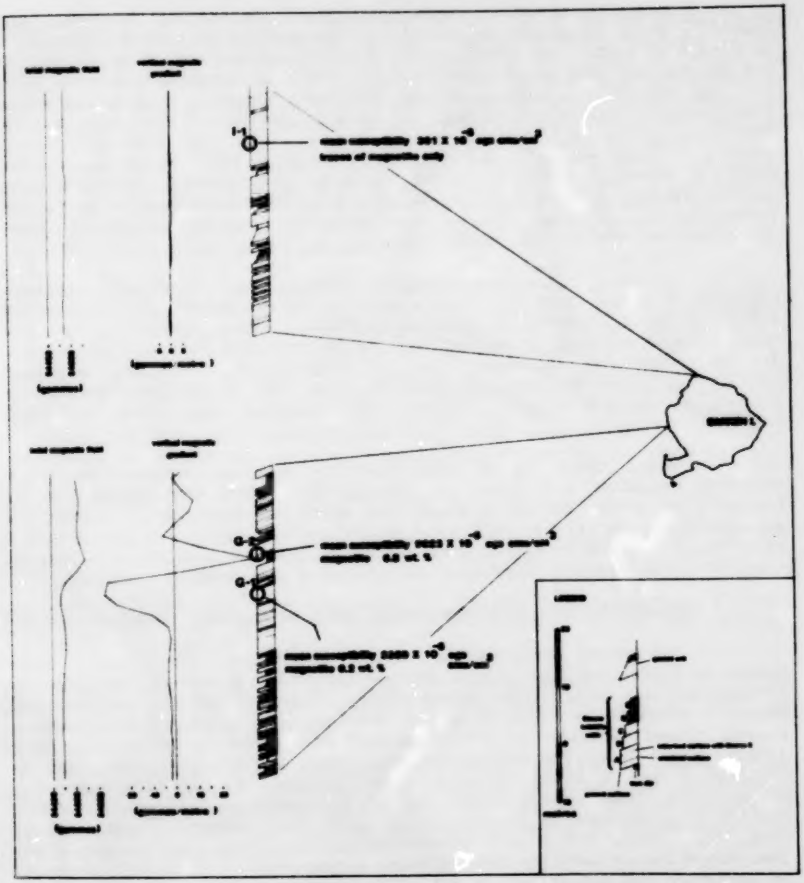


Figure 7. Diagram showing the location of magnetic susceptibility sample sites G-1, G-2, and I-1 on their lithological subsections. Total magnetic field and vertical gradient profiles are placed beside them for comparison. The vertical gradient anomaly between G-1 and G-2 is due to a susceptibility contrast caused by a four-fold difference in magnetite concentration. No magnetic anomalies are produced by low or uniform magnetite concentrations, e.g. the lithological subsection of Profile I adjacent to sample site I-1.

Magnetic anomalies (both total field and vertical gradient) are caused by small variations in magnetite concentration between adjacent beds or groups of beds. Metawacke sample G-1 has a magnetite concentration of 0.2 weight per cent which results in a low mean susceptibility (5389 x 10^{-6} cgs emu/cm^3), a correspondingly low total magnetic field value and a high negative magnetic gradient. Metawacke sample G-2 has a magnetite concentration of 0.8 weight per cent, a higher mean susceptibility (9623 x 10^{-6} cgs emu/cm^3), a higher total magnetic field value, and a high positive magnetic gradient. The variation in magnetic susceptibility between samples G-1 and G-2, caused by a four-fold difference in magnetite concentration, produces the vertical magnetic gradient and total field anomalies recorded at the sample sites.

Adjacent slate and metawacke beds commonly produce a vertical magnetic gradient anomaly, with slates being characterised by negative gradients and metawackes by positive gradients. This observation and the heavy mineral analyses of samples G-1 and G-2 indicate that most metawackes are magnetite-rich in comparision to slates, and cause the magnetic anomalies. Sites G-1 and G-2 (Fig. 7) show that it is also possible to produce a magnetic anomaly between two metawacke units with different magnetite contents.

Where there is no susceptibility contrast between beds, no magnetic anomalies are created. For example, metawacke sample I-1 in Figure 7 is almost barren of magnetite, which has resulted in a very low susceptibility of 391 x 10^{-6} cgs emu/cm^3 and a low total field value recorded at the sample site. These metawacke beds are similar to slates in terms of their magnetic signature and produce a flat magnetic response.

SEDIMENTOLOGICAL INTERPRETATIONS BASED ON MAGNETIC PROFILES

The direct relationship between magnetite concentration, mean susceptibility, and the production of magnetic anomalies may provide information of Goldenville sedimentology. For example, the vertical magnetic gradient profiles (Fig. 4) show an overall trend from larger, closely spaced anomalies in the bottom half of the section to smaller, more widely spaced anomalies toward the top. This trend may be seen best in profiles D and H which cross a large portion of the total section. Accompanying this upward smoothing of the vertical magnetic gradient profile is a decrease in the average value of total magnetic field readings (Fig. 5). These trends are interpreted as resulting from progressively less magnetite variability between beds, accompanied by an overall decrease in magnetite concentrations in metawacke upsection. There is no apparent increase in the proportion of slate upsection, so this possible cause of the decreasing total magnetic field values may be ruled out. These variations in magnetite concentration which appear to be on the kilometre-scale may cause the aeromagnetic anomalies over the Goldenville Formation.

Magnetic profiles may be useful in the recognition of sedimentary cycles within the Goldenville Formation. For example, Walker (1978) showed that thickening-upward and coarsening-upward facies sequences characterise submarine fan progradation. Since the total magnetic field values are directly proportional to the amount of metawacke present, the recognition of Walker's (1978) facies sequences (that involve increases in the proportion of sand) may be accomplished by looking at the variation in the total magnetic field values. For example, the progressive increase in the total magnetic field intensity from bottom to top (left to right) in Figure 6 corresponds to an increase in the number and thickness of metawacke beds. This may be interpreted as part of a thickening-upward and coarsening-upward cycle, typical of fan progradation. Reference back to the total field profiles for the whole study area (Fig. 5) indicates that similar cycles may be present on the scale of 100-200 m in all profiles, but are most noticeable in profile H. These cycles show a progressive upsection increase and abrupt decrease in magnetic intensity. The total magnetic field profiles may provide a rapid method by which sedimentary cycles such as these can be recognised.

Additional information on sedimentology may be gained by using the magnetic profiles to correlate beds or turbidite flow units between outcrops, thereby providing a basis to measure lateral variations in sedimentological features. Such variations would normally be difficult to measure because there is no method by which to correlate monotonous turbidite sequences in the absence of marker horizons. The lithological profiles in Figure 6 show that groups of beds with a distinctive lithological character, such as dominantly sand, tend to persist as far as 4 km parallel to strike, but that individual beds are not persistent.

CONCLUSIONS

The results of this ground magnetic study of part of the Goldenville Formation may be summarized as follows:

1. Magnetite-bearing metawacke beds in contact with metawacke or slate beds with less magnetite produce total magnetic field and vertical gradient anomalies.

2. A portable gradiometer is useful for tracing magnetic marker horizons between isolated outcrops by matching total magnetic field and vertical magnetic gradient profiles.

3. Total magnetic field profiles may detect coarsening-upward cycles within the Goldenville Formation. Vertical gradient and total field profiles may also reveal progressive vertical and lateral changes in magnetic mineral concentration that may be useful in facies modelling and provenance studies.

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DISTRIBUTION AND LOCALIZATION OF GOLD IN MEGUMA GROUP ROCKS, NOVA SCOTIA

PART 1: STRUCTURAL EFFECTS AND PRESSURE SOLUTION - PRELIMINARY RESULTS*

P. M. Clifford**, J. H. Crocket**, and F. Fueten**

ABSTRACT

Greywackes of the Meguma Group are host to quartz veins, many of which are gold-bearing. Field, petrographic and chemical analyses of the greywackes in the Liscomb Mills area of Nova Scotia show that much quartz has been removed from what are now cleavage zones; that some of this quartz has been reprecipitated as "beards" on quartz grains in lithons between cleavage planes; but that much quartz appears to have been lost from the immediate system. It is clear that pressure solution-transfer was the mechanism involved in generating cleavage and mobilizing quartz. We tentatively suggest that the "missing" quartz now appears as quartz veins, and that perhaps gold was mobilized by the same pressure solution-transfer mechanism.

RÉSUMÉ

Les grauwackes du groupe de Meguma renferment des filons de quartz, dont certains sont aurifères. L'étude sur le terrain et l'analyse pétrographique et chimique des grauwackes de la région de Liscomb Mills (Nouvelle-Écosse) montrent qu'une grande partie du quartz a été enlevée de ce qui sont maintenant des zones de clivage; qu'une partie de ce quartz a été reprécipitée sous forme d'excroissances sur les grains de quartz dans les microlithons et que le système immédiat aurait perdu une importante quantité de quartz. Il est évident qu'un processus de dissolution-transfert sous pression aurait provoqué le clivage et la mobilisation du quartz. Il est suggéré provisoirement que le quartz "perdu" apparait maintenant sous forme de filons et que l'or aurait peut-être été mobilisé par le même processus de dissolution-transfert sous pression.

INTRODUCTION

We are concerned with possible structural controls on the transfer and location of gold in rocks of the Meguma Group in Nova Scotia. Field and laboratory studies reveal abundant signs of pressure solution and related precipitation associated with mesoscopic cleavage. Chemical analyses suggest that silicate material has been moved within, and out of, the system; other analyses imply comparable transfer of Au and assoicated metal species.

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Contribution to Canada-Nova Scotia Co-operative Mineral Program, 1981-84.
Project carried by Geological Survey of Canada.

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NSDME Report 83-1

Faribault (1899) suggested that in Nova Scotia gold is hosted by quartz veins which occur in anticlinal crests as saddle reefs, after the fashion of the vein deposits of Bendigo and Ballarat in Australia. If true, this implies a regular structural control of gold deposits. More recently (Boyle, 1959; Henley et al., 1976) there have been suggestions that gold may be derived from the rock pile in which it is now found, being mobilized by pressure solution, and redeposited in relatively high concentrations elsewhere. In the Nova Scotia case, this translates to mobilization of gold from the Meguma Group rocks, and subsequent precipitation of the gold, with quartz, in quartz veins. This inference carries with it the implication that some of the quartz now in the veins has been extracted from the rock pile generally.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the continuous interest and judicious advice of J. R. Henderson; also conversations with U. Kretschmar and P. I. Wallace.

GENERAL GEOLOGY

Attention has been concentrated on the Ruth Falls Syncline, and adjacent smaller folds. These structures are exposed in the Liscomb Mills area of Nova Scotia, about 140 km east-northeast of Halifax (Fig. 1). The 1:10 000 orthophoto map 11E/01-T1 shows the outcrop very well, and all our maps have been based on it.

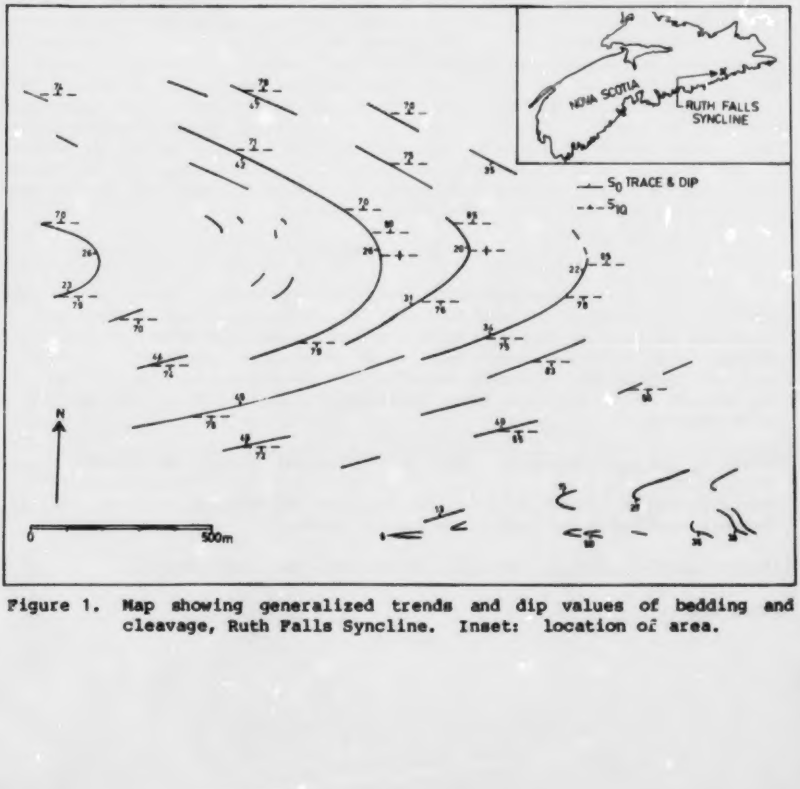

Figure 1. Map showing generalized trends and dip values of bedding and cleavage, Ruth Falls Syncline. Inset: location of area.

The rocks in these folds are of the Goldenville Formation, which, with the Halifax Formation, makes up the Meguma Group. These Goldenville rocks are now metamorphosed high-rank greywackes, at chlorite grade.

The greywackes are cyclically bedded although this is not always readily apparent. Incomplete Bouma sequences are common. Of particular interest are water escape structures. Sand volcanoes can be seen on some bedding surfaces and are particularly well displayed beyond the Ruth Falls Syncline, on some islands a few kilometres offshore (see Henderson, 1983). In a few cases, these can be seen to be connected to zones oriented at a high angle to bedding. Such zones, seen in thin sections, are devoid of phyllitic minerals, are better sorted than the general greywacke, and have a higher median grain size. They are clearly elutriation zones up which water travelled to build a sand volcano at the surface, the material of the sand volcano being the elutriated material. Such escape "pipes" are now at a high angle to, but not perpendicular to, bedding.

Water escape must have occurred prior to consolidation. Further, pipes without sand volcanoes may mean that after a bed or group of beds dewatered, the next passage of a turbidity current across the basin floor planed away any still-exposed sand volcanoes just prior to deposition of a new layer of sediment. Pipes were presumably perpendicular to bedding. It is significant that the traces of cleavage zones on ac planes are parallel to these "pipes", in that this implies that cleavage was initiated as planar zones perpendicular to bedding (see below).

STRUCTURES

These rocks are now disposed in the Ruth Falls Syncline and an attendant smaller anticline (Fig. 1). These folds have axial surfaces which strike east and are approximately vertical; they plunge at about 10° to the west. No parasitic folds have been seen.

The most conspicuous structural feature is an array of cleavage zones (CZ). Each cleavage zone is at a high, but oblique, angle to bedding, except in the axial zone where the angle is 90°. Cleavage therefore diverges systematically from parallelism to the axial surface, proceeding from axial zone to limb. Each cleavage zone is marked by a high concentration of micas and chlorite, with a strong preferred orientation of individual mineral grains subparallel to the general attitude of the cleavage zone. Widths of cleavage zones are normally in the range 1-5 mm. Cleavage zones separate lithons of "normal" rock, the lithons being, on average, from 1 cm to 5 cm wide, although variation in dimensions is considerable.

In the limbs, on ac planes, cleavage zones are anastomosing at a wavelength of 0.1-1.0 m. (It should be pointed out that few outcrops present an ac face more than 0.5 m high). On ab surfaces, or surfaces nearly parallel to ab, cleavage zones anastomose at a wavelength of 0.1 m to 1.0 m. Thus each lithon is actually a triaxial ellipsoid. The overall fabric is domainal at the metre scale.

The intensity of the cleavage in the greywackes varies with position in the fold. To quantify this in the field the number of cleavage zones per metre, (CZm^{-1}) identifiable along a line perpendicular to the lineation produced by intersection of cleavage and bedding, were measured. Measurements for rocks of roughly the same grain size ranged from 75 ± 20 CZm^{-1} in the limbs to 130 ± 20 CZm^{-1} in the core of the fold. In a single bed, increases of 40-50 cleavage planes per metre can be detected.

In thin section, cleavage zones are marked by an abundance of micas and chlorite, with their basal planes conspicuously aligned subparallel to the trend of the cleavage. Some zones appear as "seams" totally composed of phyllitic minerals, and although very narrow, the typical zone has a higher concentration of mica in the zone centre (approximately 40 per cent), decreasing more or less symmetrically to the zone margin, which is not very well defined. The other major phase in the CZ is quartz, which is less abundant there than in the lithons. The CZ quartz grains have very sharp, rectiplanar boundaries against phyllosilicates; boundaries of the same grains not in contact with phyllosilicates are irregular. The two-dimensional form of these quartz grains is quite inequant, with long axes aligned parallel to cleavage, but the grains display little or no undulatory extinction or other signs of ductile deformation (Fig. 2a). We conclude that the form of the grains, and the nature of their boundaries imply pressure solution of quartz during creation of the cleavage in its present form.

A sample calculation, taking lithon width as 10 x CZ width, with 95:5 and 70:30 percentage ratios of quartz and phyllosilicates in lithons and cleavage zones respectively, and assuming that phyllosilicates in cleavage are residual, chemically and perhaps mineralogically, suggests a loss of about 85 per cent quartz by volume from the rock volumes now represented by CZ. This represents a bulk loss of quartz from the system of about 33 per cent by volume. These values are very probably too high.

Within the lithons, there are clear signs of localised deposition of quartz, in the form of "beards" attached to sundry original quartz grains (Fig. 2b). But the amount of such deposited quartz is less than 5 per cent by volume, or no more than 25 per cent of the loss calculated above. We conclude that the process of pressure-solution plus deposition acting on these rocks has induced a net loss of quartz as a dispersed mineral phase of about 40 per cent.

Quartz Veins

Virtually all of the quartz veins seen in the Ruth Falls Syncline are in, or near, an ac position. They contain quartz, with minor amounts of chlorite. The veins are clearly postfolding, but prekink band development (see Henderson, 1983, for a more detailed discussion of quartz veins of these rocks).

Kink Folds

Kink folds have been observed and measured at 13 stations in the axial zone. All kink folds have layering abruptly inflected across the kink band boundary. Very little of the area is actually affected by these folds which are the last structural items to be impressed on the rocks, and make a trivial contribution to the total strain in these rocks.

Figure 2a. Photomicrograph of fabric in cleavage zones. Note sharp boundaries of inequant quartz (q) against phyllosilicates, and the more ragged terminations of the quartz generally.
2b. Photomicrograph of lithon fabric. Note substantial development of quartz "beards" (b) on subequant quartz.

In summary, the kink bands usually are small, with aspect ratios (width/length) of about 0.01, and widths up to 12 cm. The majority of folds show a sinistral sense of rotation. A majority of folds are also underrotated. The very few conjugate kink bands imply a stress field of:

$$\sigma_1\ 286/06;\ \sigma_2\ 028/78;\ \sigma_3\ 177/10.$$

If all kink bands are treated as if they are conjugate arrays (box folds), the stress field is:

$$\sigma_1\ 277/16;\ \sigma_2\ 097/74;\ \sigma_3\ 186/00.$$

The second stress field is based upon a wide scatter of data. We can safely say that σ_1 was oriented roughly east-west with a 10°(±) plunge to the west, and that σ_3 was horizontal, about north-south (Fig. 3).

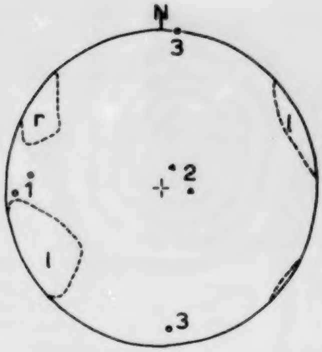

Figure 3. Principal axes of stress ($1 = \sigma_1$, $2 = \sigma_2$, $3 = \sigma_3$) determined from kink bands. Open symbols - inferred from conjugate sets; closed symbols - inferred from all kink bands. Fields are of poles of kink band boundaries: l - left-hand rotation, r - right-hand rotation. Total poles: 97.

The very sharp inflection of laminae and the equally sharp inflection of ac quartz veins caught up in kink bands, suggests that they are the latest structural event. About 75 per cent of all folds measured are underrotated, that is, geometrically they can be viewed as having positive dilation preserved (Clifford, 1969). This suggests production at shallow depths.

One peculiarity is the presence of "aborted" kink bands. These have clear boundaries oblique to layering, accentuation of layering within the band, but no rotation of layers in the band. Values of α for such bands are invariably high. We have no explation of these structures.

ROCK CHEMISTRY

If we are justified in our conclusion that cleavage developed via pressure solution processes, there should be some chemical trace of this, as a chemical difference between core and limb areas, which have markedly different cleavage densities, and between CZ and lithon anywhere.

We have analyzed six pairs of samples from correlatable layers to compare limb with core. Other samples have been split into lithon and CZ portions. For such samples, however, it has proved impossible to keep the CZ samples free of "contamination" by attached lithon material. Consequently, the contrasts between lithons and CZ are diminished somewhat from their actual levels.

Dealing first with bulk differences between axial zone and limbs (Table 1), it can be seen that, for six pairs, core versus limb, four show a loss and two show a gain of SiO_2, Fe_2O_3 and K_2O. Other components vary nonsystematically. We conclude that, overall, there is indeed differential removal of material from the core in relation to the limbs, associated with the higher density of CZ in the core.

The picture is a little different when we look at CZ versus lithons (Table 2). SiO_2 and Na_2O are depleted in CZ in every case. Always the CZ showing highest relative loss of SiO_2 also show highest relative loss of Na_2O. Al_2O_3, Fe_2O_3 and K_2O are augmented in CZ relative to lithons. Again, other components vary nonsystematically. There is little doubt that the process of cleavage generation in these rocks involves relative loss of SiO_2 and Na_2O from the rock volumes which we now recognize as CZ.

Table 1. Normalized composition, including loss on ignition, whole-rock.

Sample	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	Loss on Ign.	Total	Core/Limb
A8	78.27	10.38	2.76	1.98	0.68	2.13	2.35	0.35	0.04	0.05	1.06	100.00	Core
A1	78.95	10.10	2.70	1.33	0.87	2.18	2.27	0.50	0.05	0.04	1.00	100.00	Limb
B92	83.06	8.63	1.95	1.03	0.64	1.91	1.48	0.38	0.05	0.04	0.83	100.00	Core
F18	81.08	9.16	2.37	1.42	0.94	2.18	1.40	0.44	0.06	0.06	0.89	100.00	Limb
F15	79.29	9.96	2.82	0.87	0.95	2.81	1.44	0.46	0.05	0.10	1.23	100.00	Core
F5A	77.30	11.28	3.69	1.30	0.84	1.88	1.62	0.51	0.06	0.09	1.43	100.00	Limb
F14	75.91	11.58	4.00	1.33	1.02	2.08	1.87	0.55	0.08	0.09	1.48	100.00	Core
A45	77.77	10.35	2.67	1.23	1.76	2.80	1.32	0.41	0.07	0.06	1.54	100.00	Limb
A55	81.32	9.41	2.52	0.95	1.07	1.92	1.13	0.44	0.07	0.07	1.11	100.00	Core
A54	82.32	8.93	2.34	1.03	0.73	1.98	1.08	0.50	0.04	0.07	0.94	100.00	Limb
A50	79.71	9.80	2.74	1.35	1.14	1.97	1.34	0.53	0.07	0.08	1.26	100.00	Core
A49	79.52	9.37	2.64	1.55	1.03	2.83	1.22	0.49	0.09	0.07	1.18	100.00	Limb
A47	80.76	9.06	2.42	1.35	0.75	2.66	1.14	0.48	0.03	0.07	1.28	100.00	Limb
F12	80.02	9.86	2.81	1.14	0.82	2.23	1.30	0.55	0.06	0.07	1.14	100.00	0
A53	80.32	9.68	2.86	1.06	0.78	2.15	1.34	0.51	0.06	0.08	1.18	100.00	0
A52	81.61	9.19	2.37	1.09	1.18	1.67	1.01	0.46	0.01	0.06	1.35	100.00	0
A50A	80.22	8.72	2.36	2.21	1.12	2.76	0.93	0.46	0.06	0.07	1.07	100.00	X
A50C	79.46	9.90	2.76	1.35	1.11	2.02	1.35	0.53	0.07	0.08	1.36	100.00	X
A50E	79.64	9.52	2.68	0.77	1.81	2.22	1.31	0.54	0.08	0.09	1.35	100.00	X
A50D	64.47	7.67	1.95	1.26	13.00	1.63	1.04	0.40	0.25	0.33	8.00	100.00	X
A50F	77.74	10.94	3.27	0.96	1.07	2.23	1.67	0.60	0.06	0.08	1.39	100.00	X
A50B	81.03	9.31	2.42	1.06	1.09	1.94	1.24	0.51	0.05	0.08	1.26	100.00	X

X- Samples used to check composition of different flow units in one bed.

0- Bed cannot be properly correlated.

Table 2. Normalised composition, including loss on ignition, cleavage (C) versus lithon (L).

Sample	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	Loss on Ign.	Total
F5AC	70.80	14.01	4.97	2.03	1.02	2.16	2.44	0.64	0.09	0.12	1.73	100.00
F5AL	74.73	12.21	4.46	1.37	1.05	1.94	1.94	0.59	0.08	0.09	1.53	100.00
	74.29	12.28	4.55	1.38	1.06	2.19	1.95	0.58	0.09	0.11	1.53	100.00
F5AC	70.22	13.87	5.32	2.08	1.13	2.08	2.76	0.67	0.09	0.11	1.67	100.00
F5AL	74.71	11.87	4.48	1.83	0.99	1.95	1.90	0.55	0.07	0.11	1.54	100.00
F5AIC	75.10	11.85	4.13	1.23	1.08	1.70	2.74	0.63	0.07	0.09	1.38	100.00
F5AIL	79.89	9.58	2.96	1.26	0.84	2.04	1.86	0.49	0.07	0.06	0.95	100.00
F5A50C	67.83	16.08	4.58	1.42	1.33	1.89	3.59	0.83	0.08	0.13	2.24	100.00
F5A50L	78.74	9.88	3.19	0.97	1.47	2.19	1.35	0.49	0.07	0.08	1.57	100.00
F14C	70.31	13.46	5.61	2.22	0.98	2.09	2.51	0.63	0.12	0.08	2.00	100.00
F14L	74.35	12.22	4.46	1.41	1.04	2.19	2.07	0.56	0.10	0.09	1.51	100.00
A49C	72.54	13.66	4.03	1.37	1.15	2.12	2.50	0.71	0.07	0.12	1.72	100.00
A49L	78.48	9.89	3.00	1.39	1.72	1.87	1.26	0.50	0.08	0.08	1.74	100.00

Generally, there has been removal of material to give CZ, and a broader scale transfer and loss of material from core to limb and out of the local system. Presumably the pathways for these transfers were along the CZ or at the CZ-lithon interface; it is not likely that material was transferred across CZ. The most plausible mechanism for this chemical readjustment is pressure solution with some local reprecipitation, a view supported by petrographic evidence.

SUGGESTED HISTORY

The overall sequence of events envisaged for the generation of cleavage and the production of the folds is as follows:

1. Unconsolidated sediment lost water, via water escape structures in particular.

2. CZ developed, postdewatering, and continued into the folding episode. CZ are now parallel to water-escape channels, and so were initially bedding-normal. Development of CZ has involved removal of silica, so an episode of pressure solution, with maximum pressure exerted parallel to bedding, occurred prior to, and perhaps during, the early stages of fold formation.

3. Subsequent growth of the fold led to the present structure, with fanning cleavage. Cleavage now fans symmetrically about the axial plane but is not generally normal to bedding. There is no sign of slippage in or on CZ, so the rotation of CZ from bedding-normal to bedding-oblique positions may be ascribed to an episode of flattening superimposed on a simple deflection geometry. (Preliminary estimates suggest a flattening of 20-25 per cent but this is based upon only two data sets).

4. Quartz beards attached to quartz grains in the lithons are composed of rectilinear fibres. It follows that during the period of growth of such beards the strain was irrotational. The alignment of fibres parallel to cleavage traces, without any sign of distortion suggests a late stage growth.

Figure 4 shows, schematically, the sequence of events, against an arbitrary time scale.

DISCUSSION

It is apparent that pressure solution was largely responsible for the production of the cleavage zones; chemically, such zones are consistently depleted in SiO_2 and Na_2O. But there is an apparent substantial loss from the system of SiO_2, the reprecipitated "beards" do not represent more than 25 per cent of the mobilized SiO_2. We suggest that the mobilised SiO_2 which is not now seen as "beards" actually appears as the quartz veins of the area. If pressure solution mobilised SiO_2, it is conceivable that it also mobilised the gold which occurs in some veins. It is this possibility that is the focus of continuing work.

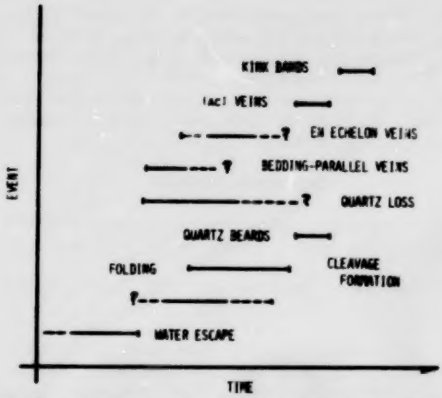
KINK BANDS
(ac) VEINS
EN ECHELON VEINS
BEDDING-PARALLEL VEINS
QUARTZ LOSS
QUARTZ BEARDS
FOLDING
CLEAVAGE FORMATION
WATER ESCAPE
EVENT
TIME
?

Figure 4. Proposed sequence of events in the Ruth Falls Syncline. Position of bedding-parallel and en echelon veins are based upon coastal data, and are not locally inferrable.

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DISTRIBUTION AND LOCALIZATION OF GOLD IN MEGUMA GROUP ROCKS, NOVA SCOTIA

PART 2: IMPLICATIONS OF BACKGROUND GEOCHEMISTRY AND CLEAVAGE DEVELOPMENT - A PRELIMINARY REPORT*

J. H. Crocket**, P. H. Clifford**, F. Fueten** and A. Kabir**

ABSTRACT

Gold and arsenic were determined by radiochemical neutron activation analysis in metagreywackes and slates from Meguma Group rocks. Averages for 22 greywackes from the Ruth Falls Syncline are 1.19 ppb gold and 2.30 ppm arsenic. Averages for 38 slates from Liscomb Point and nearshore islands are 1.72 ppb gold and 2.54 ppm arsenic. These values are background levels as the sampled areas are unmineralized.

A study of gold and arsenic distribution between limb and axial zone domains of the Ruth Falls Syncline suggested that no consistent redistribution of these metals on a scale of hundreds of metres has occurred in response to deformation associated with the folding. The partition of gold and arsenic between cleavage and lithon domains in Ruth Falls metagreywackes is usually characterized by higher metal content in cleavage domains. Pressure solution of quartz is an important factor in cleavage domain upgrading of gold content.

RÉSUMÉ

La teneur en or et en arsenic des métagrauwackes et des schistes du groupe de Meguma a été déterminée grâce à l'analyse par activation radiochimique des neutrons. Vingt-deux échantillons de grauwackes provenant du synclinal de Ruth Falls ont une teneur moyenne en or de 1,19 ppb et en arsenic de 2,30 ppm. Trente-huit échantillons de schistes provenant de Liscomb Point et des îles près du littoral ont une teneur moyene en or de 1,72 ppb et en arsenic de 2,54 ppm. Ces chiffres sont des valeurs de fond puisque les régions échantillonnées ne sont pas minéralisées.

L'étude de la répartition de l'or et de l'arsenic entre les flancs et la zone axiale de synclinal de Ruth Falls suggère qu'il n'y a pas eu répartition uniforme de ces métaux sur des centaines de mètres en réponse a la déformation associée au plissement. La répartition de l'or et de l'arsenic entre les zones de clivage et les microlithons des métagrauwackes de Ruth Falls est généralement caractérisée par une teneur plus élevée en métaux dans les zones de clivage. La dissolution sous pression du quartz est un facteur important dans l'accroissement de la teneur en or des zones de clivage.

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Project carried by Geological Survey of Canada.
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INTRODUCTION

Native gold and arsenopyrite are concentrated in quartz veins hosted by the flysch-type Cambro-Ordovician sedimentary rocks of the Meguma Group in eastern Nova Scotia. Most of the productive veins are bedding parallel and commonly localised at the centre of elliptical domes along anticlinal crests according to Faribault (1899). Some studies including those of Faribault (1899) and Keppie (1976) argue that folding and vein formation are essentially synchronous whereas others, for example Graves and Zentilli (1982), would have vein formation predate folding. It is therefore of interest to determine the distribution of gold and arsenic with respect to both small and large scale features related to deformational history. One facet of this study has been an evaluation of gold and arsenic distribution in cleavage and adjacent lithon domains in metagreywacke on a hand specimen scale. A companion study has been carried out on the gold and arsenic variation in fold limb and axial zone domains in single beds of metagreywacke. The structure on which these studies were conducted was the Ruth Falls Syncline, Ecum Secum area (Clifford et al., 1983).

The ultimate origin of gold in Meguma Group quartz veins is enigmatic. Boyle (1966), McBride (1978) and Graves and Zentilli (1982) argue that the Meguma Group rocks represent an adequate source for the mineralisation, and stress the importance of regional greenschist metamorphism as an effective process to mobilise and concentrate metals. Glasson and Keays (1978), on the other hand, do not believe the host rocks of the Clunes field in Victoria, Australia, represent a sufficient reservoir to account for the gold mineralization. Their study is relevant to the Meguma zone in view of the very similar geological history and mineralization characteristics of the Victoria gold fields. To evaluate the potential of the Meguma Group as a source domain, an evaluation of the background levels of the metals of interest is of importance. Thorpe and Thomas (1976) have carried out such a study on drill core from the Oldham district. We have determined the background levels of gold and arsenic at two locations in the Ecum Secum area to increase the data base, evaluate regional variation, compare metal levels in greywacke and slate, and to gain insight into the mineralogical siting of gold in unmineralised environments.

ACKNOWLEDGEMENTS

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SAMPLING AND ANALYTICAL PROCEDURES

Samples were collected from two localities in the Ecum Secum area including the Ruth Falls Syncline (Clifford et al., 1983) and Liscomb Point and nearshore islands (Fig. 1). In the Ruth Falls Syncline metagreywacke outcrops were sampled from the limb and axial zone domains of individual beds with a spacing of approximately 100 m between samples. Several samples of the same bed were collected at one site to establish metal variation on a local scale (A50 series). At Liscomb Point and on Barren, Crooks and Goose islands (Fig. 1) slate outcrops were sampled across

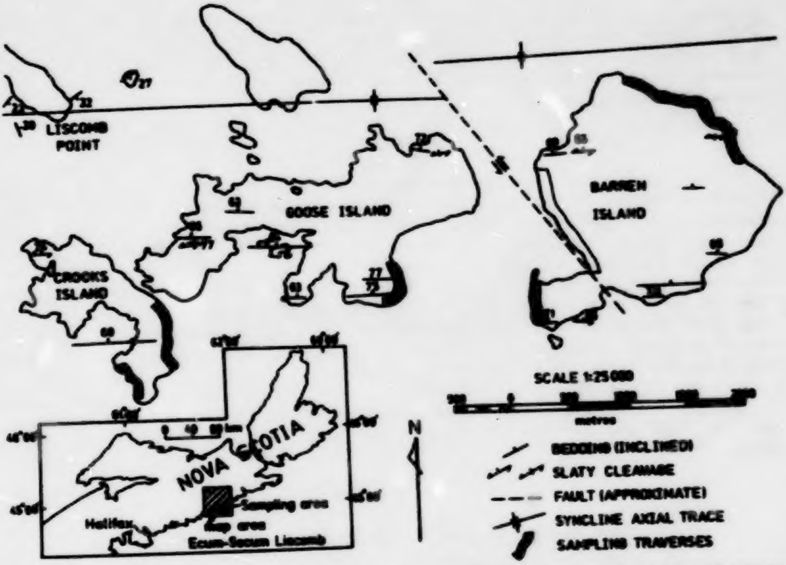
LISCOMB POINT
GOOSE ISLAND
CROOKS ISLAND
BARREN ISLAND
NOVA SCOTIA
Halifax
Sampling area
Map area
Ecum-Secum Liscomb
N
SCALE 1:25000
metres
BEDDING (INCLINED)
SLATY CLEAVAGE
FAULT (APPROXIMATE)
SYNCLINE AXIAL TRACE
SAMPLING TRAVERSES

Figure 1. Location map showing sampling traverses for collection of slate samples from Goose, Crooks and Barren islands, and Liscomb Point.

approximately 2500 m of stratigraphy. Both sites are in unmineralised localities in the Goldenville Formation.

Greywacke and slate hand specimens of approximately 0.5 kg were passed through a jaw crusher and disk grinder to obtain fragments of about 0.5 mm. Final reduction of 100 gm of this material to -200 mesh was done in a ceramic shatter box. Slabbing of greywacke samples to obtain cleavage-lithon slices is described in Clifford et al. (1983) and subsequent reduction was carried out as above. About 300 mg of -200 mesh powder was taken for analysis.

Gold and arsenic determinations were carried out by radiochemical neutron activation analysis using a procedure similar to that described by Kronborg and Steinnes (1975). Briefly, samples were irradiated for 0.5 h in a neutron flux of 1×10^{13} neutrons/cm^2/sec in the McMaster University reactor. Following a 3 to 4 day decay period samples and appropriate gold and arsenic carriers were dissolved by an alkali peroxide fusion and subsequently dissolved in HCl. Thioacetamide solution was added and precipitated by heating. Gold and arsenic coprecipitate on the organic material which is filtered, washed and then counted.

The composite gamma ray spectrum of ^{198}Au and ^{76}As was taken on a 4000 channel gamma spectrometer coupled to an intrinsic coaxial germanium detector. Chemical yields of gold and arsenic are determined by a one minute reirradiation of the recovered carrier. The sensitivity limits are approximately 0.1 ppb for gold and 200 ppb for arsenic. The gold and arsenic levels in the samples are sufficiently high that no samples were below the sensitivity limits.

RESULTS

Analytical results for the Ruth Falls Syncline rocks are tabulated in Tables 1 and 2, together with the arithmetic mean and standard deviation for the entire whole rock suite. In Table 1 the A8, A1 to the A55, A54 pairs represent two samples from the same bed, one from the core or axial zone and the other from the gold limb. Samples A49 and A47 are from the limb domain of the same bed and are separated by tens of metres. The series F12, A53, A52 are from the axial zone domain but probably are not from the same bed. The A50 series are samples representing a 250 cm stratigraphic thickness of amalgamated beds, and are briefly described in the footnote to Table 1.

The cleavage-lithon data are presented in Table 2 and a summary of the gold and arsenic contents of 38 slate samples from four sites is given in Table 3.

DISCUSSION

Heavy Metals in Ruth Falls Syncline Metagreywacke

BACKGROUND METAL LEVELS

The Ruth Falls Syncline rocks represent an unmineralized environment lacking auriferous bedding parallel quartz veins. The gold and arsenic contents are regarded as background values thought to represent mainly the metal content inherited as sedimentation, but subject to redistribution during structural evolution of the Syncline. Comparison of the statistics on the Ruth Falls suite with comparable bodies of data is severely limited as available compilations usually include arenaceous rocks representative of several depositional environments. However, the study of Thorpe and Thomas (1976) provides comparable data for gold obtained by a similar analytical technique. Thorpe and Thomas (1976) report a maximum likelihood value for the mean gold content of 39 greywacke samples from a drill core taken near Oldham as 0.62 ppb. The hole is apparently several hundred metres from the nearest known auriferous vein in the district. The arithmetic mean for Ruth Falls metagreywacke is 1.19 ± 1.05 ppb gold for 22 samples. Both averages should provide an estimate of the background gold content of Meguma Group greywackes. The difference in the two estimates is approximately a factor of two. This may reflect real regional variation or may arise because the maximum likelihood value is a better estimator of true mean value than the arithmetic mean. Alternatively, differences in the neutron activation analytical technique employed in the two studies may introduce a bias. Both the Oldham and Ruth Falls averages indicate that Meguma Group greywackes are not significantly higher in gold than sandstones in general. Estimates of average gold in sandstones, siltstones, greywacke and subgreywacke compiled by Boyle (1979) and Crocket (1974) are 13 and 3.0 ppb respectively. These estimates, although not specifically

Table 1. Gold and arsenic contents of metagreywackes, Ruth Falls Syncline, Meguma Group, Nova Scotia: comparison of metal distribution in the axial zone and limbs of the fold.

Sample	Code	Au, ppb	As, ppm
A8	Core	0.85	2.1
A1	Limb	0.79	2.2
B92	Core	0.36	1.7
F18	Limb	1.2	2.5
F15	Core	1.2	1.2
F5A	Limb	3.6	1.25
F14	Core	3.2	3.2
A45	Limb	0.83	2.1
A55	Core	0.22	1.0
A54	Limb	0.34	3.6
A50	Core	0.75	2.9
A49	Limb	1.15	1.9
A47	Limb	0.56	1.7
F12	Core	3.5	1.5
A53	Core	0.91	3.8
A52	Core	2.7	1.5
A50A	Core	0.39	2.1
A50B		0.54	2.7
A50C		0.47	2.1
A50D		0.45	2.6
A50E		1.4	1.9
A50F		0.71	5.0
Average for A50 Series		0.66±0.38	2.28±0.35
Aggregate statistics	$\overline{X}$	1.19	2.30
	r	0.22-3.6	1.0-5.0
	σ	1.05	0.96
	n=22		

Note:
The A50 series are from one outcrop consisting of approximately 2.5 m of amalgamated greywacke beds. Five beds are A unit Bouma sequence rocks and one A50D represents a B unit. The arsenic value for A50F is not included in the series average.

Table 2. A comparison of gold and arsenic contents of cleavage plane-lithon pairs from Ruth Falls Syncline metagreywackes.

Sample		Au, ppb	As, ppm
F5A1	cleavage	2.1	4.3
	lithon	1.1	3.0
F5A(i)	cleavage	5.8	2.0
	lithon	1.3	1.6
F5A(ii)	cleavage	7.3	2.0
	lithon	1.6	1.6
A49	cleavage	1.2	2.6
	lithon	0.62	1.7
F14	cleavage	1.5	2.2
	lithon	6.1	2.9
F5A50	cleavage	0.61	2.4
	lithon	1.3	2.1

Note: F5A(i) and F5A(ii) are two different cleavage-lithon pairs from the same hand specimen.

relevant to sandstones deposited by turbidity mechanisms, suggest that Meguma Group greywackes carry a normal or slightly depleted compliment of gold.

The background level for arsenic suggested by the Ruth Falls data is 2.30 ppm. Unfortunately, it cannot be established by comparison with lithogeochemical data if this arsenic level is an average for sandstones. According to Onishi (1969) 1 ppm may be taken as an average arsenic content for sandstone, but the data base is extremely limited and no significance is attached to the difference between Onishi's estimate and the Ruth Falls average.

One comparative aspect of the arsenic and gold distribution may be noted. Arsenic and gold concentrations do not correlate significantly on a sample-to-sample basis. The gold-arsenic correlation coefficient is $r=0.23$, a value which is not significant at a 10 per cent probability level when tested against a Student's t distribution. This behaviour is in contrast to the strong association of these metals characteristic of mineralized quartz veins in Meguma Group rocks. A tentative inference from this observation is that the gold-arsenic association in quartz veins is established by and during the mineralization process. This in turn suggests

Table 3. Gold and arsenic contents of Meguma Group slates, Ecum Secum area, Nova Scotia.

Locality	n^1	Au, ppb			As, ppm			CO_2, wt.%		
		$\overline{X}^1$	σ^1	r^1	$\overline{X}$	σ	r	$\overline{X}$	σ	r
Barren Island	17	1.87	3.35	0.40–14	2.16	1.1.6	0.95–5.3	0.15	0.14	0.01–0.50
Crooks Island	14	1.38	0.64	0.65–2.5	1.96	0.36	1.5–2.9	0.07	0.04	0.01–0.14
Goose Island	5	0.96	0.44	0.42–1.5	1.69	1.06	0.75–3.1	0.06	0.04	0.02–0.12
Liscomb Point[2]		2.1			18					0.09
		7.2			6.0					0.07
Aggregate statistics	36	1.72	2.44	0.40–14	2.54	2.80	0.75–5.3	0.11	0.11	0.01–0.50

1. n-number of samples; $\overline{X}$-arithmetic mean; σ- one standard deviation; r-range
2. Two samples were analyzed from this locality. Data for each sample are given.

that the inherent availability of the metals to ore solutions, a factor which is probably more dependent on mineralogical siting of the metal than on absolute concentration, is an important factor in the generation of ore fluids.

DISTRIBUTION OF METALS IN FOLD LIMBS AND AXIAL ZONE

An early generalization from studies of gold vein distribution in the Nova Scotia fields was that veins were preferentially sited in the axial zones of folds (Faribault, 1899). Clifford et al. (1983) cite evidence that pressure solution processes have caused considerable mobilization of silica. To test the possibility that gold and arsenic were redistributed on a large scale by such processes, a series of Ruth Falls metagreywacke beds were sampled in limb and axial zone domains. In general the lateral separation of samples along strike was about 100 m. Six sets of samples, A8-A1 to A50-A49-47 as listed in Table 1, were collected for this purpose.

The major element data (Clifford et al., 1983, Table 1) do not suggest consistent compositional trends related to sample location on the fold limb or axial zone. Gold and arsenic concentrations are also inconsistent with respect to fold geometry, tentatively suggesting that no unidirectional migration of metals on a scale of hundreds of metres has occurred in response to regional stress gradients in the Ruth Falls structure. This assessment is necessarily qualitative because, in addition to redistribution of metals induced by deformation, other factors probably contribute to metal heterogeneity within the same bed. In particular, some variation is probably inherited from sedimentation.

To assess such variation six samples A50A to A50F (Table 1) were taken from a single outcrop representing a 250 cm stratigraphic thickness consisting mainly of a series of amalgamated A unit Bouma sequence greywackes. Rather consistent gold and arsenic results were obtained suggesting that relatively uniform metal contents are inherited from sediment deposition and lithification processes. A basis for recognizing variation in excess of that expected of such processes can be established by comparing the differences in metal content of core-limb pairs with differences between samples in the A50 series. Specifically, the average difference between an individual sample and the A50 series average is calculated for each metal. This average difference is 40 per cent for gold and 27 per cent for arsenic. Differences between core and limb values in excess of 40 and 27 per cent are interpreted as greater variations than those expected from processes of sediment deposition and lithification. On this basis it is suggested that, in four cases the differences in gold and arsenic contents of core and limb samples exceeds the variation expected from sedimentation alone. These pairs are B92-F18, F15-F5A, F14-A45 and A55-A54 for gold and B92-F13, F14-A45, A55-A54 and A50-A49-A47 for arsenic. Presumably the gold and arsenic contents of these samples have been affected by post-depositional processes which may be related to the structural history of the Ruth Falls Syncline. Three of the four core-limb pairs which are significantly different in gold content are characterized by higher gold in the limb while the fourth pair shows the opposite trend. Two pairs are characterized by higher arsenic in the core and two by higher arsenic in the limb. Therefore, it does not appear that clear and consistent metal trends related to the regional structural fabric are evident in the Ruth Falls Syncline, although there is a tendency for a specific bed to carry more gold in the limb than in the axial zone.

DISTRIBUTION OF METALS BETWEEN CLEAVAGE PLANES AND LITHONS

A prominent anisotropy developed during deformation of the Ruth Falls rock is cleavage. As shown in Part 1 (Clifford et al., 1983) systematic and consistent compositional differences between cleavages and adjacent lithons characterize Ruth Falls greywackes with lower SiO_2 contents and higher Al_2O_3, Fe_2O_3, K_2O and TiO_2 contents in cleavage domains compared with the adjacent lithon. Gold and arsenic also vary between cleavage and lithon domains. In a given sample the two elements vary sympathetically in that both are always higher in the same domain. Cleavage-lithon pairs differ much more in gold content than in arsenic. On average the difference for gold is a factor of 3.2 compared with 1.3 for arsenic. Thus cleavage represents a major anisotropy with respect to gold in that adjacent layers of rock within 2 to 3 mm of each other may differ in gold content by up to 4.5 times (e.g. sample F5A).

Unlike the very consistent compositional trends found for the major elements, gold and arsenic are not always partitioned between cleavage and lithon domains in the same sense. In four of six cases, all of which are samples from the fold limbs, the cleavage domains are higher in metal than the adjacent lithons. This relationship appears consistent on a hand specimen scale in that two different cleavage-lithon pairs from the same sample, F5A, give nearly identical results for both metals. In the remaining two cases, which are samples from the axial zone, gold and arsenic are higher in the lithon. Whether any significance can be attached to the differing sense of metal concentration in limb and axial zone settings is difficult to assess. The dominant trend is the gold-arsenic enrichment in cleavage domains on the fold limb which may result, in part, from pressure solution of quartz.

The essential mineral components of the greywackes are quartz, feldspar, chlorite and mica. One process thought to be involved in cleavage development is pressure solution of quartz. As loss of silica is suggested by the comparative SiO_2 contents of cleavage-lithon pairs, such loss must be reflected in a proportionate increase in other minerals in the cleavage domain as reflected in increases in Al_2O_3, K_2O and other components. This process would increase the gold and arsenic contents of the cleavage domain if quartz is significantly lower in gold than chlorites, micas or any accessory minerals not attacked in the pressure solution process. Based on a compilation of literature data Crocket (1974) found an average gold content for quartz and feldspar of 1.7 and 2.0 ppb which is significantly lower than averages for mica of 6.0 ppb and magnetite-ilmenite of 6.7 ppb. It was also noted that accessory minerals, for example sphene, zircon and apatite are extremely variable in gold content and often very high compared to the parent whole-rock. While accessories and minerals of low modal abundance such as the micas or iron oxides are usually minor contributors to the total gold compliment of igneous rocks, their importance as gold contributors to the very quartz-rich Ruth Falls greywackes may be significantly enhanced if these rocks are subject to selective removal of gold-poor quartz. In samples such as F5A1 or A49 where the gold enhancement of the cleavage domain is approximately twice that of the lithon an increase in the proportion of phyllosilicate through quartz removal may well be sufficient to account for the observed difference. Where a marked gold increase in the cleavage domain is found, such as the 4.5-fold enrichment in F5A (i,ii), upgrading of the proportion of some accessory gold concentrator minerals in addition to phyllosilicates may be required. Two tenative generalizations are drawn from these considerations. Cleavage development is often accompanied by the formation of localized domains enriched in gold in comparison with the immediate host rock. Secondly, the pressure-temperature regime necessary to generate an ore fluid from the indigenous gold in Meguma Group greywackes, presumably must break down or recrystallize the phyllosilicate minerals.

Gold and Arsenic Contents of Meguma Group Slates

Slates are the second major lithology of Meguma Group rocks. Background gold and arsenic levels were evaluated by sampling an area in the Ecum Secum-Liscomb Point district with no known mineralization. The sampling was carried out on Barren, Crooks and Goose islands, as well as Liscomb Point (Fig. 1). These localities consist of Goldenville Formation rocks and offer superb exposures of slate units. The stratigraphy includes a few quartz veins, mainly en echelon type, but no auriferous veins have been reported.

The averages reported in Table 3 are the simple arithmetic means of all analyses - 1.72 ppb and 2.54 ppm for gold and arsenic respectively. In comparison with the greywacke averages of 1.19 ppb gold and 2.30 ppm arsenic, the shales are higher in gold by a factor of 1.4 and higher in arsenic by a factor of 1.1. As is characteristic of many background gold distributions, however, the simple arithmetic average is strongly biased by a few samples of unusually high gold content, so that the arithmetic mean is greater than the true mean. This situation applies to the Ecum Secum slate data where one sample from Goose Island contains 14 ppb gold. If this sample, which exceeds the arithmetic mean by greater than 2 σ is excluded, the remaining 37 samples average 1.39 ppb gold. The arsenic data are also subject to the same consideration in that one sample (Liscomb Point) exceeds the 2 σ range. The recalculated arsenic average, excluding the value of 18 ppm is 2.12 ppm, arsenic. These constrained averages are regarded as better estimators of the true mean metal content of the slates.

Literature compilations yield rather variable estimates of the average gold content of shale. Crocket (1974) reported an average of 2.5 ppb, and Boyle (1979) an average of 8 ppb gold. Onishi (1969) noted that arsenic is highly variable in shales and recommends an average for shales of 13 ppm arsenic. The most directly comparable data are those of Thorpe and Thomas (1976) who consider 2.0 ppb gold as the best mean for slates for the Oldham drillhole.

Factors commonly cited as important in concentration of metals in shales are adsorption on clay minerals, coprecipitation on diagenetic iron sulphide and reduction by organic matter (Boyle, 1979; Onishi, 1969). Total carbon was determined as a measure of the significance of organic matter. The average carbon content expressed as CO_2 equivalent is 0.11 weight per cent. By comparison with an average for clays and shales of

0.67 per cent C or 2.45 per cent CO_2 (after Ronov, 1958), the Meguma Group slates are very low in carbon. Deformation has probably affected the carbon content significantly with some attendant loss; nevertheless, the lack of any significant positive correlation of gold or arsenic with carbon content, and the very low carbon contents, suggest that concentration of metals by organic carbon was probably not a significant factor in controlling the primary gold and arsenic contents of Meguma Group slates.

The sampling area represents approximately 2500 m of stratigraphy with a coverage along strike of about 6000 m. Within this area no significant regional trends in gold or arsenic content are evident. The Barren Island gold average of 1.87 ppb is considerably higher than that of Goose Island, but is strongly biased by one sample with 14 ppb gold. This sample contains 1.1 ppm arsenic and 0.13 weight per cent CO_2, and is therefore not unusual with respect to either of these constituents. If this sample is neglected, the Barren Island gold average is 1.12 ppb which is probably a better estimate of the true mean. The most anomalous locality is Liscomb Point where two high arsenic and one high gold values were obtained. Unfortunately, the Liscomb Point data base is currently too small to evaluate the signifance of these two samples.

Two comparative aspects of this study and that of Thorpe and Thomas (1976) are worth comment. Similar average gold contents were obtained in both studies - 1.4 in this study compared with 2.0 in Thorpe and Thomas' study. Our samples were obtained from outcrop. Metal loss as a result of weathering is a potential problem. However, the relatively close agreement with the result of Thorpe and Thomas, which was obtained on drill core, suggests that no major bias has been introduced by weathering. Secondly, Thorpe and Thomas' data suggest that the slates are significantly higher in gold than greywackes, in that their averge gold contents are 2.0 and 0.62 ppb respectively. Our averages are 1.4 and 1.2 ppb gold for slate and greywacke respectively, and it is suggested that these differences are statistically insignificant. This difference may result from real differences in the gold content of the various areas sampled or may be caused by other fators briefly noted in previous discussion. In genetic modelling which envisages a source of gold within Meguma host rocks, the relative potential of greywacke and slate as gold sources is probably essentially independent of the actual background gold levels if our averages are accepted. Factors such as differences in the mineralogical siting of gold in the two lithologies or differences in permeability of the rocks to fluids are probably of greater significance in controlling the relative contribution of metal from greywacke and slate to ore fluids.

CONCLUSIONS

The principal findings of the study are that cleavage development in Meguma Group greywacke resulted in redistribution of gold, usually with an increase in gold content in the cleavage domain. A similar trend is found for arsenic. A second finding is that slate and greywacke from unmineralised areas differ little in gold or arsenic contents, and are not unusually high in these metals.

Pressure solution of quartz is probably a very important factor in the redistribution of gold in cleavage domains and may upgrade the average gold content of the rock if remobilized silica is removed.

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AN OCCURRENCE OF GOLD AND SILVER WITHIN THE SOUTH MOUNTAIN BATHOLITH OF SOUTHWESTERN NOVA SCOTIA: POTENTIAL LOW GRADE LARGE TONNAGE MINERALIZATION

G. A. O'Reilly

During a petrological and geochemical study of an area of the South Mountain batholith hosting W-Sn mineralization near Westfield, Queens County significant values of gold and silver have been encountered (Fig. 1, Table 1). Gold mineralization in the Westfield area has been known since 1888 associated with a large quartz vein hosted by the metasedimentary Meguma Group (Malcolm, 1976). The Jumbo vein, as it is known, was reported by Bailey (1896) to contain 0.25 oz Au/ton and 2 oz Ag/ton from a sulphide rich ore sample. A sample of arsenopyrite and quartz collected by the author from the Jumbo vein dump assayed 1.22 oz Au/ton (37.19 ppm) and contained anomalous Sn, Pb and Ag (Table 1) thus confirming the value reported by Bailey.

Further geological mapping in the area by the author in 1980 indicated a probable association of the Jumbo vein and previously unknown W-Sn mineralization with a metasomatized granite cupola developed in the endocontact zone of the nearby South Mountain batholith (O'Reilly, 1981). The study defined a paraintrusive suite, the result of progressive metasomatism in an apical and peripheral portion of the batholith. The paraintrusive suite includes K-feldspathized granite porphyry, albitized and greisenized granite and greisen. Quartz vein stockworks and large quartz fissure lenses, an example of which is the Jumbo vein, have emanated outward from the cupola into the exocontact metasedimentary rocks.

Some samples of the K-feldspathized granite porphyry were found to contain highly anomalous Ag and Au values (Table 1, Fig. 1). One sample (A7C-7530) was found to contain 10.94 ppm Au (0.358 oz/ton) and a number of samples ranged from 10-30 ppm Ag (0.33-0.98 oz/ton). These analyses are considered significant for the following reasons. The samples of porphyry were randomly collected for age dating purposes with no prior knowledge of Ag and Au mineralization within this particular phase. At present there are little criteria for distinguishing mineralized from the unmineralized porphyry. Free Au or Ag was not visible in any samples although some amount of sulphides (pyrrhotite and chalcopyrite) occurs disseminated in most of the porphyry samples collected. The K-feldspathized granite porphyry comprises upwards of 90 per cent of the exposed paraintrusive rocks on Figure 1. A good potential may exist for a large tonnage low grade situation although the extent and spatial distribution of the anomalous zones remains to be systematically outlined.

The metallogenetic specialization of Ag in rocks of the South Mountain batholith has been reported by Chatterjee (1983), but a similar specialization of Au in the granitic rocks of the Meguma Terrane, although alluded to, has never been confirmed.

The association of gold in granitic rocks, although new to Nova Scotia, has been documented in other granitic terranes throughout the

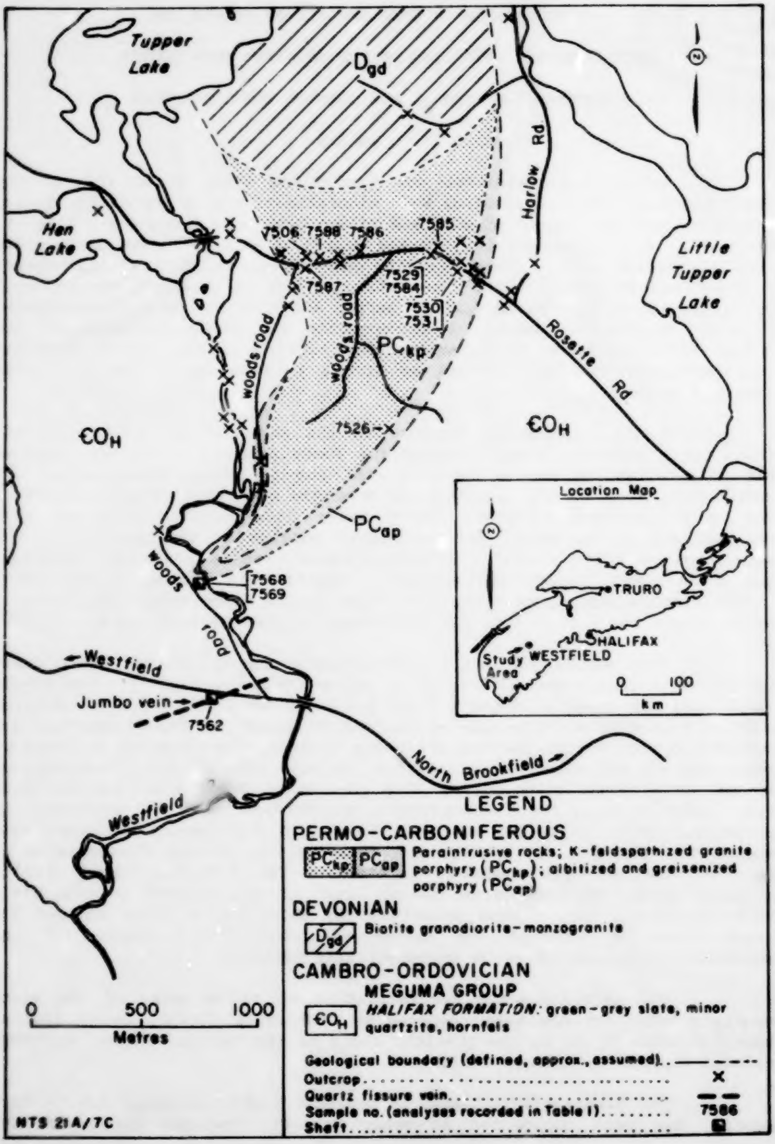

Tupper Lake
Dgd
Harlow Rd
Hen Lake
Little Tupper Lake
7506
7588
7586
7585
7587
7529
7584
7530
7531
woods road
woods road
PCkp
Rosette Rd
€OH
€OH
7526
PCap
Location Map
TRURO
HALIFAX
Study Area
WESTFIELD
0
100
km
woods road
7568
7569
Westfield
Jumbo vein
7562
North Brookfield
Westfield
0
500
1000
Metres
NTS 21A/7C
LEGEND
PERMO-CARBONIFEROUS
PCkp
PCap
Paraintrusive rocks; K-feldspathized granite porphyry (PCkp); albitized and greisenized porphyry (PCap)
DEVONIAN
Dgd
Biotite granodiorite-monzogranite
CAMBRO-ORDOVICIAN
MEGUMA GROUP
€OH
HALIFAX FORMATION: green-grey slate, minor quartzite, hornfels
Geological boundary (defined, approx., assumed)
Outcrop
Quartz fissure vein
Sample no. (analyses recorded in Table I)
7586
Shaft

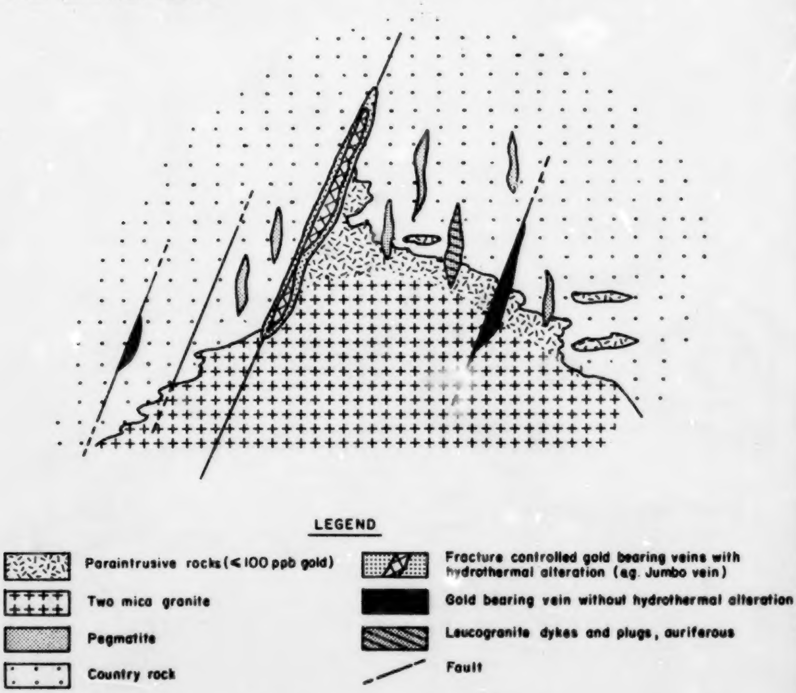
Figure 1. General geology and sample locations of the Westfield W-Sn-Mo-Ag-Au prospect.

Table 1. Geochemical analyses of samples from Westfield prospect. Locations on Figure 1.

Sample No.	A7C-7506	A7C-7526	A7C-7529	A7C-7530	A7C-7531	A7C-7562*	A7C-7568*	A7C-7569*	A7C-7584	A7C-7585	A7C-7586	A7C-7587	A7C-7588
Majors (%)													
SiO_2	72.05	73.94	69.57	70.56	71.66	-	-	-	69.61	70.31	69.45	72.73	70.17
TiO_2	0.37	0.28	0.53	0.55	0.65	-	-	-	0.43	0.41	0.46	0.34	0.43
Al_2O_3	13.77	14.03	14.73	14.86	14.57	-	-	-	14.89	14.80	15.22	14.03	14.76
Fe_2O_3	0.55	0.73	0.26	0.72	0.86	-	-	-	0.30	0.41	0.57	0.53	0.49
FeO	1.76	1.35	2.68	2.28	1.36	-	-	-	2.70	2.20	2.60	1.80	2.50
MnO	0.052	0.028	0.082	0.045	0.038	-	-	-	0.10	0.10	0.11	0.06	0.08
MgO	0.58	0.44	0.83	0.79	0.70	-	-	-	0.90	0.89	0.88	0.71	0.83
CaO	0.90	0.42	1.48	0.43	0.38	-	-	-	1.56	1.34	1.21	1.12	1.69
K_2O	4.51	5.16	4.22	4.19	3.87	-	-	-	4.33	4.54	4.46	4.54	4.15
Na_2O	3.14	3.16	3.19	3.45	4.43	-	-	-	3.29	3.68	3.54	3.41	3.52
H_2O^+	0.83	0.83	1.13	1.44	1.30	-	-	-	1.00	0.90	1.30	0.90	1.30
H_2O^-	<0.01	<0.01	0.03	0.01	0.27	-	-	-	0.10	0.10	0.10	0.10	0.10
P_2O_5	0.172	0.136	0.194	0.165	0.150	-	-	-	0.21	0.19	0.19	0.18	0.18
CO_2	0.053	0.106	0.562	0.088	0.140	-	-	-	0.45	0.60	0.10	0.10	0.20
Total	98.73	100.60	99.49	99.57	100.38	-	-	-	99.87	100.47	100.19	100.55	100.40
Traces (ppm)													
Cu	18	24	33	102	33	53	44	26	37	43	24	21	33
Pb	14	12	18	16	20	230	5480	3000	21	24	26	24	24
Zn	47	36	92	95	126	12	21800	428	90	200	93	78	81
Sn	20	62	37	36	35	60	6.1	5.3	-	-	-	-	-
W	120	<4	<4	4	4	<4	<4	<4	11	5	4	1	5
Mo	1.6	4.0	4.0	3.0	2.8	6.5	9.0	7.4	3.0	3.5	1.5	2.5	2.0
Be	5.8	6.6	7.7	4.6	5.6	3.0	2.0	3.0	-	-	-	-	-
Bi	0.6	1.4	1.6	3.4	3.4	-	-	-	-	-	-	-	-
Ba	400	450	510	640	610	-	-	-	400	480	550	410	390
Rb	198.3	191.5	213.4	248	178	-	-	-	210.2	250	200	195.6	200
Sr	73.1	56.0	100.4	80	97	-	-	-	102.6	150	150	88.9	120
U	3.3	4.9	5.7	4.7	2.2	-	-	-	6.6	4.7	4.3	3.3	5.4
Th	5	4	7	7	5	-	-	-	7.5	10	8	8	8
F	1150	250	950	430	620	-	-	-	700	910	610	540	640
B	16	20	35	36	45	-	-	-	-	-	-	-	-
Li	61	33	94	61	55	-	-	-	103	100	89	68	90
Sr	-	-	-	-	-	-	-	-	150	130	170	110	140
Ag	0.2	<0.1	0.2	0.8	0.3	11.6	117.0	77.0	30	11.8	<0.2	<0.2	22
Au	-	-	0.008	10.94	-	37.19	0.160	0.160	0.010	0.009	-	-	0.005

*Dump samples of quartz and polymetallic sulphides world. Boyle (1979, p. 295) described Au and Ag deposits associated with acidic and basic intrusions in western Canada, Chile, U.S.S.R. and Zaire. The host intrusions consist of porphyry dykes and sills, granite and granodiorite stocks and the peripheries of granitic batholiths. The mineralizing episode was commonly accompanied by alteration such as sericitization, silicification, feldspathization, pyritization and carbonatization. Westfield shows many of these features described by Boyle (1979).

Crouzet et al. (1979) described gold deposits associated with the Massif Central of France. The similarities of granitoid terranes of Eastern Canada with those of Western Europe are discussed by Strong (1980). The summary model of Crouzet et al. (1979) for gold deposits associated with the Massif Central is presented in Figure 2 and compares very closely with features observed in the Westfield prospect. Note that the model has been translated to English and modified slightly for comparison with Westfield.


LEGEND
Paraintrusive rocks (< 100 ppb gold)
Two mica granite
Pegmatite
Country rock
Fracture controlled gold bearing veins with hydrothermal alteration (eg. Jumbo vein)
Gold bearing vein without hydrothermal alteration
Leucogranite dykes and plugs, auriferous
Fault

Modified after Crouzet et al., 1979

Figure 2. Summary model of gold mineralization associated with the Massif Central of France. Modified to compare with the Westfield prospect.

A paper on the geology and geochemistry of the Westfield prospect is near completion with anticipated publication in the fall of 1983. A detailed description of the paraintrusive rocks and associated W-Sn-Mo-Ag-Au mineralization will be in the paper. This note gives only a brief description of some of the results of the study pertaining to Au-Ag mineralization. This is done to alert exploration interests in the Province that granitoids of the Meguma Terrane have valid potential for hosting economic deposits of precious metals as well as an already established excellent potential for deposits of Sn-W-U and related elements.

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BASS RIVER COMPLEX: PART OF THE AVALONIAN BASEMENT IN NOVA SCOTIA

H. V. Donohoe, Jr.

INTRODUCTION

Preview

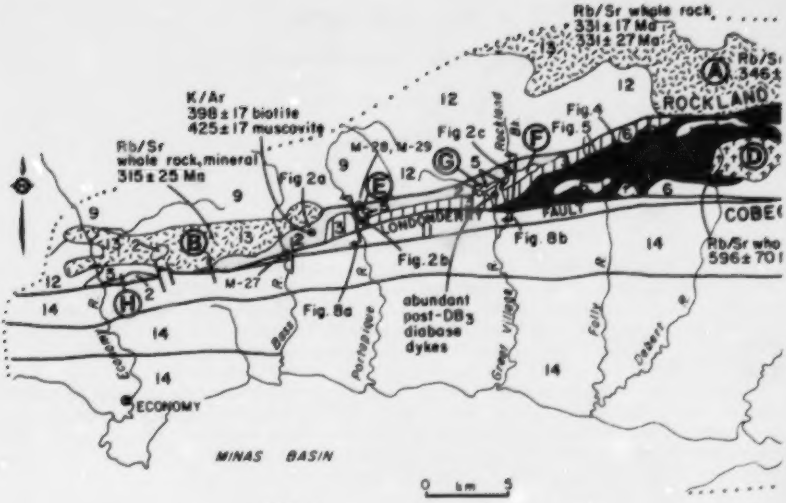
Basement rocks older than Late Hadrynian have been identified in the Cobequid Highlands. Here the gneisses and schists of the Bass River and Mt. Thom Complexes constitute the sialic basement to the Avalon Zone. The work by Donohoe and Wallace (in preparation) and the detailed investigations by Cullen (in preparation; Donohoe and Cullen, 1983) have shown that the Bass River Complex is comprised of two lithotectonic units: a "basement" of older gneisses and a "cover" of metasedimentary and metavolcanic rocks (Donohoe and Cullen, 1983). At present these two lithotectonic elements have not been identified in the Mt. Thom Complex. This paper will concentrate on the Bass River Complex because it is better exposed and more is known about it than the Mt. Thom Complex.

Background

The gneissic character of some rocks of the Bass River Complex was first recognized and described by Honeyman (1874). In his mapping which he began in the 1860's, he considered the "...diorite, quartzites, and some gneissic strata...to be...probably older than the Lower Silurian-...(Honeyman, 1874)." Later he considered the age of some of these rocks to be Archean (Honeyman, 1881). Mapping by Fletcher (1892, 1905), Weeks (1948), and Stevenson (1958) tended to obscure the importance of these strongly deformed and metamorphosed rocks by assigning them to a Silurian age or older. During the Geological Survey of Canada mapping program under the direction of D. G. Kelley between 1962 and 1968 these rocks were described as the mylonite schist zone by Eisbacher (1967) and Eisbacher and Kelley (1966) and assigned no specific age by Eisbacher (1967). Donohoe (1976), Donohoe and Wallace (1978), and Wallace and Donohoe (1977) were uncertain of the exact age of the rocks and listed the age as either pre-Silurian or Proterozoic-Paleozoic. With the publishing of the Rb/Sr whole rock-mineral isochron age of 504 ± 27 Ma for the MacCallum Settlement pluton (A on Fig. 1) by Cormier (1980) the age of the Bass River Complex was established as Cambrian or older. Since then Donohoe and Wallace (1980, 1982) and Gaudette et al. (1983) have argued for a Hadrynian or older age.

Location

The Bass River Complex is exposed along the southern margin of the Cobequid Highlands between the Londonderry and Rockland Brook Faults. Inliers are exposed as far east as the West North River, but the main outcrop area lies between the Chiganois River in the east and the Economy River to the west (Fig. 1), a distance of 55 km.


Rb/Sr whole rock
331± 17 Ma
331± 27 Ma
13
Rb/S
346±
A
ROCKLAND
12
12
K/Ar
398 ± 17 biotite
425 ± 17 muscovite
Rb/Sr
whole rock, mineral
315 ± 25 Ma
M-28, M-29
Fig 2c
Rockland
Fig.4
Fig. 5
F
G
5
6
D
9
9
9
Fig 2a
E
12
6
13
B
13
2
3
LONDONDERRY
11
FAULT
COBE
Fig. 8b
Fig. 2b
14
Rb/Sr who
596± 70
12
5
2
H
M-27
14
Fig. 8a
abundant
post-DB$_3$
diabase
dykes
14
Economy
Bass
Portapique
Great Village
Folly
Debert
14
14
ECONOMY
MINAS BASIN
0 km 5

LEGEND

EARLY, LATE CARBONIFEROUS AND LATE TRIASSIC

14	Undifferentiated HORTON, WINDSOR, CANSO, RIVERSDALE, PICTOU, and FUNDY GROUPS

EARLY TO "MIDDLE" CARBONIFEROUS

13	(13) Syenogranite to alkali feldspar granite
12	(12) Diorite
11	*LONDONDERRY FORMATION:* grey, green sandstone, siltstone
10	*NUTTBY FORMATION:* red-brown sandstone, grey siltstone

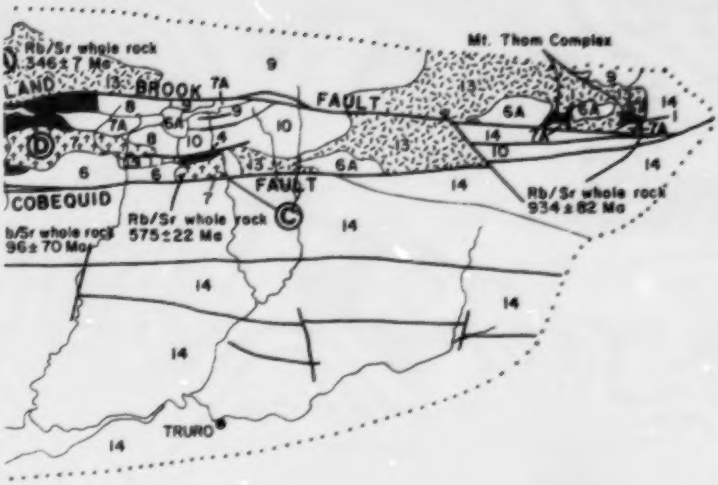
LATE ORDOVICIAN TO DEVONIAN

9	Undifferentiated sedimentary and volcanic rocks

EARLY CAMBRIAN OR OLDER

8	Unnamed sandstones, siltstones
7, 7A, 6, 6A	(7) Granodiorite to syenogranite; (7A) Granite (may be younger) (6) Diorite; (6A) Diorite (may be younger)

Figure 1. Geological map of the Bass River Complex. Location of plutons shown by letter; location of figures shown by numbers.


Mt. Thom Complex
Rb/Sr whole rock
346±7 Ma
LAND
BROOK
FAULT
FAULT
COBEQUID
D
C
Rb/Sr whole rock
575±22 Ma
b/Sr whole rock
96±70 Ma
Rb/Sr whole rock
934±82 Ma
TRURO
1
6
6A
7
7A
8
9
10
13
14

HADRYNIAN OR OLDER

5 (5) Granite gneiss

BASS RIVER COMPLEX (2 to 4)
FOLLY RIVER SCHIST: green, mafic metavolcanic rocks
3 *GAMBLE BROOK SCHIST:* grey quartzite, biotite ± garnet + quartz schist

2 | 1 (2) *GREAT VILLAGE RIVER GNEISS:* grey feldspar-amphibole-quartz gneiss; amphibolite; granitoid gneiss
(1) MT. THOM COMPLEX: granitoid gneiss; feldspar-biotite-garnet gneiss; amphibolite

Plutons	Granite Gneiss Bodies
Ⓐ Hart Lake-Byers Lake	Ⓔ Portapique River
Ⓑ Pleasant Hills	Ⓕ Rockland Brook
Ⓒ McCallum Settlement	Ⓖ Great Village River
Ⓓ Debert River	Ⓗ Economy River

Boundaries

Two major faults, the Rockland Brook and Londonderry Faults (Fig. 1), enclose the Bass River Complex in a large ellipsoidal-shaped fault block. The length of the fault block is at least 55 km; the width reaches a maximum of 5 km at the East Folly River.

At the eastern end of the outcrop area the Bass River Complex is in contact with the Devono-Carboniferous by the Huttby Formation (Fig.1). The contact is not exposed and detritus from the local lithotypes of the Bass River are not found in the conglomerates in the Huttby.

South and west of the Huttby Formation large undeformed diorite and granite plutons form the boundaries of the Bass River Complex.

An inlier of the Bass River Complex is found on the West North River. It is isolated by intrusions and a fault (Fig.1). The boundary with the McCallum Settlement pluton is an intrusive contact.

GEOLOGICAL RELATIONSHIPS

Mapable Units

Three formal units described by Donohoe and Wallace (1980; in preparation) comprise the Bass River Complex: Great Village River Gneiss, Gamble Brooke Schist, and Folly River Schist. The distribution of these units is shown on Figure 1. The Great Village River Gneiss forms one lithotectonic unit while the other two formations form a second lithotectonic unit.

GREAT VILLAGE RIVER GNEISS

Most of the rocks in the Great Village River Gneiss are dark coloured gneisses composed of biotite ± hornblende ± chlorite ± feldspar (mainly oligoclase-andesine) + quartz. This is the most common lithotype. Between the Portapique River and Bass River biotite-muscovite granitoid gneisses form the Great Village River Gneiss. From the Bass River westward to the end of outcrops the unit is composed of coarse grained and fine grained amphibolite.

GAMBLE BROOK SCHIST

Distinctive white to light grey quartzites characterize this unit. Interlayered with the quartzites are darker-coloured biotite ± muscovite ± quartz schists. These lithotypes are distinctive over the entire outcrop area. Locally impure carbonate layers are interlayered with the quartzites. Good exposures of all these lithotypes are found in the quarry at the southern end of Folly Lake.

FOLLY RIVER SCHIST

This unit comprises dark green mafic schists and mafic metavolcanic rocks. Locally a great amount of lithologic diversity may be found in the Folly River Schist. Red and purple coloured "iron formation" outcrops between the Folly and Debert Rivers (Fig. 1). White to light grey quartzite is interlayered with some of the volcanic rock. The quartzite may be present due to structural mixing of the Folly River Schist and the Gamble Brook Schist. Locally carbonate layers are present in some of the "iron formation".

Intrusive Rocks

Three groups of igneous rocks have intruded the rocks of the Bass River Complex. The first two groups were intruded prior to some of the deformation and metamorphic episodes. Group one consists of the orthogneisses in the Great Village River Gneiss. The separate and mapable granite gneiss bodies form group two. The third group consists of all igneous rocks which postdate the deformation episodes in the Bass River Complex.

GROUP ONE

The orthogneisses in the Great Village River Gneiss comprise two lithotypes: amphibolite and granitoid gneisses. They are interpreted as orthogneisses because their mineralogy is similar to undeformed rocks of gabbroic-dioritic and granitic composition. These orthogneisses are found in local areas and have not been mapped over large areas. The amphibolite outcrops on the Bass River and westward. The granitoid gneisses are found between the Portapique and Bass Rivers.

The amphibolite is composed of hornblende and plagioclase (andesine-labradorite) with minor amounts of chlorite, epidote and accessory minerals. The granitoid gneisses are composed of biotite, muscovite, quartz, and feldspar.

The relative ages of these two orthogneiss units has not been established because they are not in contact with each other. Both gneisses have been deformed during the DB_1 deformation (described later under DB_1 Deformation).

GROUP TWO

Granite gneiss and fine grained amphibolite compose group two. Five orange-coloured granite gneiss bodies (Fig. 1) and many smaller dyke- or stock-like forms outcrop in the Bass River Complex. These gneisses consist of orthoclase, quartz, hornblende (some altered to chlorite), minor plagioclase (oligoclase), and accessory minerals (zircon, apatite, sphene). The granite gneiss bodies' boundaries are usually concordant with the SB_2 foliation. Small "veins" have been found which are not concordant to the SB_2 foliation.

Most of the granite gneiss bodies contain tabular-shaped, fine grained, and green-coloured amphibolite. The contacts with the granite gneiss are fine grained and concordant with the SB_2 foliation. Away from the boundary the grain sise of the amphibolite increases. The tabular shaped amphibolite is found in a few outcrops of all three formations of the Bass River Complex.

The granite gneiss bodies have no evidence of the DB_1 deformation and are extensively deformed by the DB_2 and DB_3 deformations.

The crosscutting relationships of the granite gneiss bodies on both a map scale (Fig. 1) and outcrop scale and their mineralogy suggest an intrusive origin. The tabular geometry and fine grained contacts of the amphibolite also suggest an intrusive origin. The granite gneiss bodies were probably hornblende granites intruded by diabase dykes prior to the DB_2 and DB_3 deformations. The age of the intrusions is Hadrynian or older for reasons described under the heading Radiometric Ages.

GROUP THREE

All of the intrusive rocks in this group crosscut DB_2 and DB_3 sturctures. Individual intrusions are composed of diorite, granodiorite, or granite. The Debert River pluton (D on Fig. 1) intruded Folly River Schist and contains xenoliths of both the Folly River and Gamble Brook Schists as well as of the diorite pluton to the south. The McCallum Settlement pluton (C on Fig. 1) intruded the Folly River Schist and contains xenoliths of the two schist formations. At the western end of Bass River Complex exposure area the Complex was intruded by the Pleasant Hills pluton (B on Fig. 1). A large block of Great Village River Gneiss is surrounded by granite and is probably a roof pendant (Fig. 1). Many other small intrusions of granite and diorite, shown on Figure 1, have intruded the Complex.

The youngest intrusions are the undeformed diabase dykes which have intruded the Bass River Complex and the undeformed dioritic and granitic intrusions. The diabase is found as single dykes, dyke swarms, and as small stocks. Generally the dykes are concordant with the orientation of the SB_2 foliation. Locally in the area around the Great Village River the dykes exceed 50 per cent of the outcrop.

Deformations and Metamorphism

As a whole the Bass River Complex was subjected to three major deformations and several minor kink banding events (Donohoe and Wallace, 1980; in preparation). The Great Village River Gneiss has been deformed at least three times: once more than the other two units. The deformations and the units affected are shown in Table 1.

Table 1. Deformations affecting units of the Bass River Complex.

		DEFORMATIONS					
	UNIT	DB_1		DB_2		DB_3	
		SB_1	SB_2	FB_2	LB_2	SB_3	FB_3
BASS RIVER COMPLEX	Folly River Schist		X	X (bedding folded)	X	X	X
	Gamble Brook Schist		X	X (bedding folded)	X	X	X
	Great Village River Gneiss	X	X	X (metamorphic foliation folded)	X	X	X

DB_1 DEFORMATION

Evidence for this deformation is confined solely to the Great Village River Gneiss. Remnants of compositional layering found in the closures of FB_2 folds suggest a previously existing metamorphic foliation. Various examples of this are shown in Figure 2. These folds are found in the granitoid gneisses west of the Portapique River and in gneisses exposed in the Rockland Brook region. The extent of metamorphism accompanying the DB_1 event is not clear. Work by Cullen (in preparation) suggests that some of the almandine garnets and tabular sillimanite crystals in the Great Village River Gneiss may have grown prior to the DB_2 deformation event. These crystals are partly crushed and broken.

DB_2 DEFORMATION

The DB_2 deformation affected all of the Bass River Complex and the granite gneiss bodies. The prominent fabric elements of this deformation are the ubiquitous SB_2 metamorphic foliation with accompanying mineral lineation. Regionally the orientation of the SB_2 foliation, shown in Figure 3, is fairly constant. The accompanying LB_2 mineral lineation has somewhat more variation in orientation and plunge, but generally is shallow plunging to the east. The variation is probably due to younger FB_3 folding.

In the Gamble Brook and Folly River Schists many folds have been observed with the SB_2 foliation forming the axial plane foliation. One of these is shown in Figure 4. Where the compositional layering crosses the closures of the folds no additional foliation can be observed. These layers are interpreted as bedding by M. Cullen, R. A. Jamieson, and P. I. Wallace (personal communication, 1981, 1982) and myself. We support this conclusion by citing the lack of a folded foliation in FB_2 fold closures in these two units and the variety of distinct, adjacent composition layers. Examples from the East Folly River show layers of red-brown-purple coloured iron formation interlayered with grey carbonate, white to grey quartzite, or biotite-quartz schist. In the quarry at the southern end of Folly Lake adjacent layers of carbonate, quartzite, and biotite-quartz schist are folded.

The regional geometry of FB_2 folds is not known because of extensive local refolding by FB_3 folds. Most probably the FB_2 axial surfaces were originally shallow dipping (possibly recumbent) based on the attitude of the SB_2 foliation shown in Figure 3. The East Folly River exposures (Fig. 1) show a FB_2 fold which is sketched in Figure 4. The S_0-SB_2 intersections suggest an overturned synform. This has been the only megascopic FB_2 fold found. Several macroscopic folds were found along the East Folly River and in the quarry south of Folly Lake.

Biotite-staurolite-almandine assemblage is common in the pelitic rocks of the Gamble Brook Schist and the Folly River Schist. The mafic schists of the Folly River Schist have the assemblage hornblende-andesine (oligoclase-andesine)-epidote. The mineral assemblages indicate a lower almandine amphibolite facies of metamorphism. This grade of metamorphism continued after the development of the SB_2 fabric. In Figure 5 euhedral almandine has overgrown the SB_2 fabric in the pelitic layers of the Folly River Schist. Most probably the garnets grew post-DB_2 and pre-DB_3 (Fig. 6).

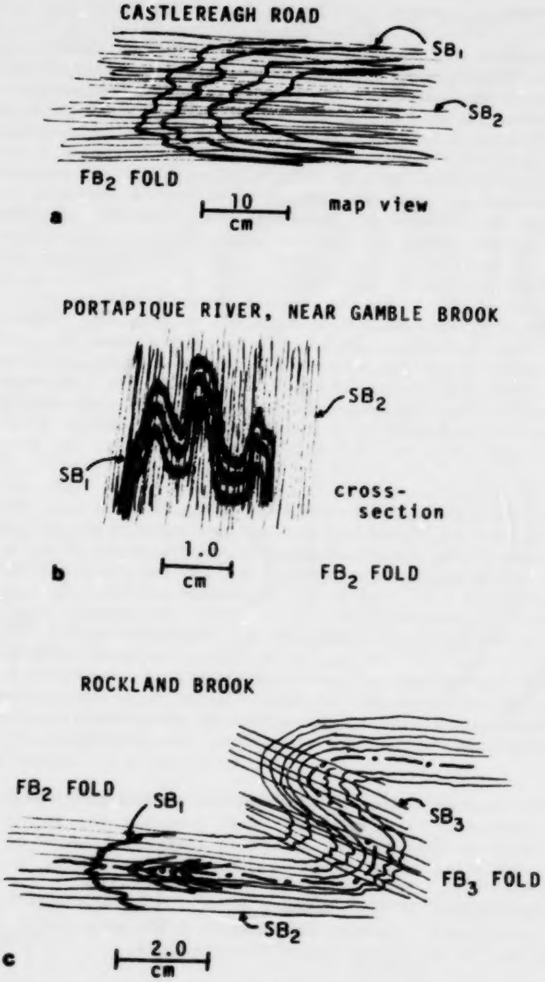
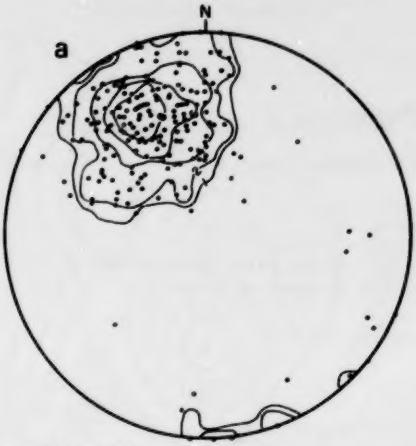
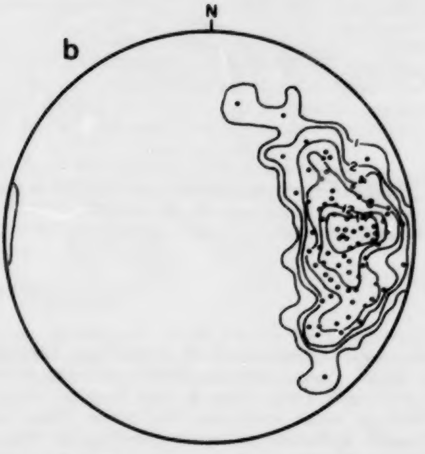

CASTLEREAGH ROAD
SB_1
SB_2
FB_2 FOLD
a
10 cm
map view
PORTAPIQUE RIVER, NEAR GAMBLE BROOK
SB_2
SB_1
cross-section
b
1.0 cm
FB_2 FOLD
ROCKLAND BROOK
FB_2 FOLD
SB_1
SB_3
FB_3 FOLD
SB_2
c
2.0 cm

Figure 2. SB_1 metamorphic foliation folded by FB_2 folds in the Great Village River Gneiss. Locations are shown on Figure 1.



Contoured at 1,2,4,6,8%



Contoured at 1,2,4,8,12,14%

after Eisbacher (1967) in part

Figure 3. Equal area projections of DB_2 structural data from the entire Bass River Complex.
a) 186 poles to SB_2 foliation.
b) 77 LB_2 mineral lineations (some data from Eisbacher, 1967).

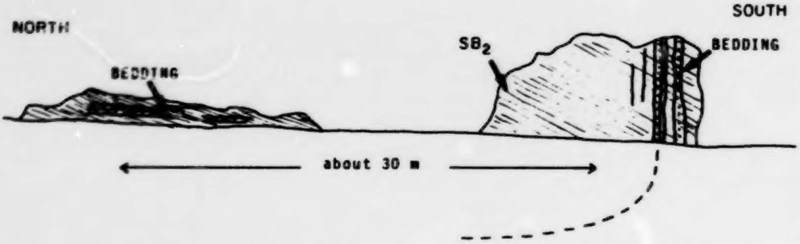

NORTH
SOUTH
BEDDING
SB_2
BEDDING
about 30 m

Figure 4. FB_2 fold of the Folly River Schist on the East Folly River. Location is shown on Figure 1.

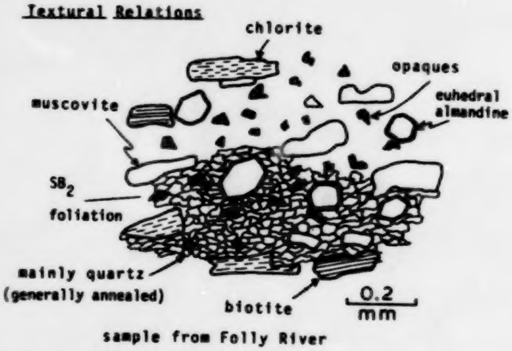

Textural Relations
chlorite
opaques
euhedral almandine
muscovite
SB_2 foliation
mainly quartz (generally annealed)
biotite
0.2 mm
sample from Folly River

Figure 5. Post-DB_2 almandine garnet growth in quartzites of the Folly River Schist. Location is shown on Figure 1.

DB_3 DEFORMATION

The last major deformation to affect the Bass River Complex produced folds with axial planes oriented east-northeast to west-southwest. Wavelengths of these folds range from 0.1 km to 2 km. The folds have shallow to moderate dipping axial surfaces; the hinge lines are variably oriented and generally have moderate plunges. The axial planes and hinge line attitudes are shown in Figure 7.

Locally a crenulation cleavage is found in the tightest closures. In some locations this crenulation cleavage has become an incipient fabric enhanced by the rotation or growth of muscovite and/or chlorite (depending on lithotype). Previously existing micas are generally broken or folded in the closure areas of small scale folds.

BASS RIVER COMPLEX

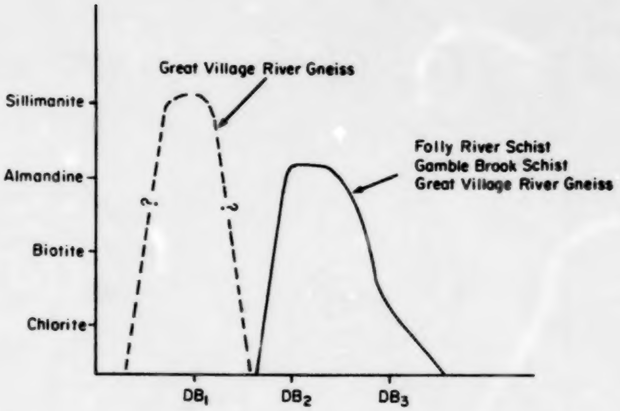


Figure 6. Structural and metamorphic history of the Bass River Complex.

The present geometrical orientation of the SB_2 foliations in the three formations and the granite gneiss bodies has resulted from the DB_3 deformation. The folds are common in outcrop scale. Typical cross-sections showing the FB_3 geometry are shown in Figure 8.

Chlorite and muscovite have grown along the axial surfaces of some FB_3 folds and crenulation cleavage surfaces. The maximum metamorphic grade was probably chlorite zone of Greenschist Facies. During the DB_3 deformation the metamorphic grade for all three formations was considerably less than during DB_2.

YOUNGER DEFORMATIONS

Two types of younger deformation have affected the Bass River Complex. Variously oriented kink bands bend and/or break the SB_2 foliation planes. None of the kink bands have been observed cutting FB_3 folds. Generally the kink bands are not common.

The second type of a younger deformation is mylonitization associated with movement on the bounding faults (Rockland Brook and Londonderry Faults). Mylonitization along the Rockland Brook Fault has deformed the Bass River Complex metamorphic rocks up to 600 m from the fault. It appears as a fine grained crushing along very closely spaced foliation planes oriented parallel to the fault and dipping steeply to the south. The granite of the Hart Lake-Byers Lake pluton (A) is mylonitized. At the western end of the fault the Pleasant Hills pluton (B) intruded across the fault.

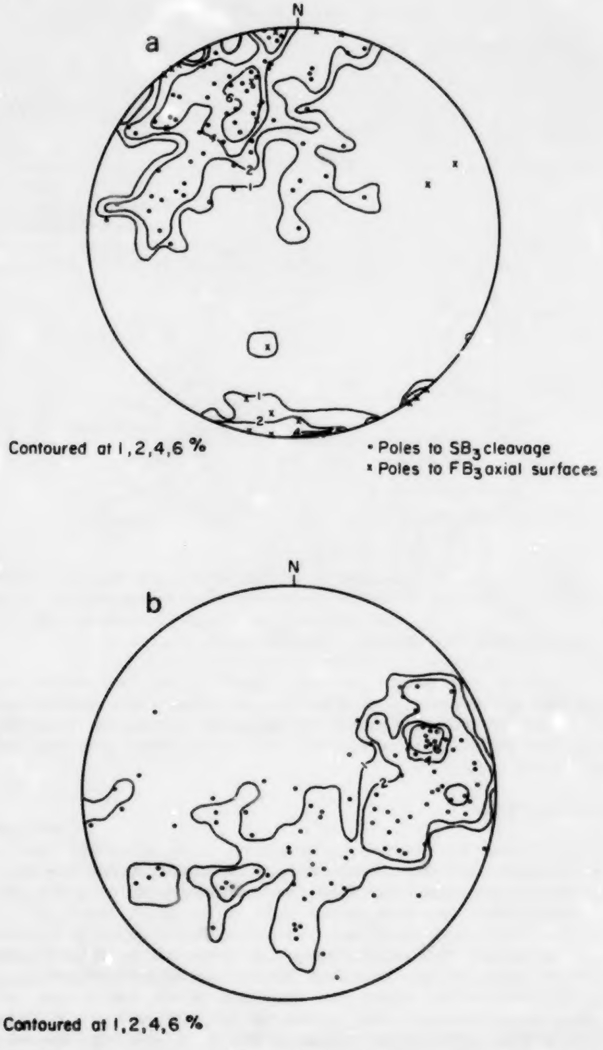


Figure 7. Equal area projections of DB_3 structural data from the entire Bass River Complex.
a) 82 poles to SB_3 cleavage and FB_3 axial surfaces.
b) 99 hinge lines to FB_3 folds.

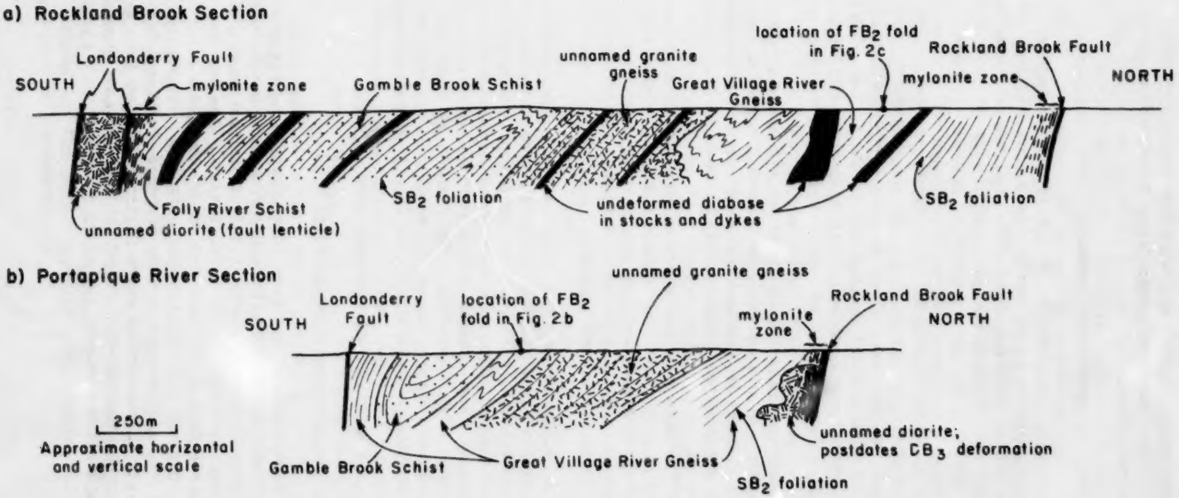

a) Rockland Brook Section
SOUTH
Londonderry Fault
mylonite zone
Gamble Brook Schist
unnamed granite gneiss
Great Village River Gneiss
location of FB_2 fold in Fig. 2c
Rockland Brook Fault
mylonite zone
NORTH
Folly River Schist
unnamed diorite (fault lenticle)
SB_2 foliation
undeformed diabase in stocks and dykes
SB_2 foliation
b) Portapique River Section
SOUTH
Londonderry Fault
location of FB_2 fold in Fig. 2b
unnamed granite gneiss
mylonite zone
Rockland Brook Fault
NORTH
250m
Approximate horizontal and vertical scale
Gamble Brook Schist
Great Village River Gneiss
SB_2 foliation
unnamed diorite; postdates DB_3 deformation

Figure 8. Schematic structural cross-sections of the Bass River Complex. Present configuration of fold geometries results from the DB_3 deformation (FB_3 folds). Location of sections are shown on Figure 1.

The mylonitization along the Londonderry Fault occurs only in the Bass River Complex. The Namurian Londonderry Formation on the southern side of the fault is not affected.

MINERAL OCCURRENCES

Known mineral occurrences in the Bass River Complex are few. They are either associated with one of the principal boundary faults or they are found parallel to bedding or the SB_2 metamorphic layering. The source of information for description and location is Donohoe (1982) and Donohoe and Wallace (1982).

Occurrence M27 (Nova Scotia Department of Mines and Energy, Mineral Occurrence Number 11E/05-6; Fig. 1) is magnetite and pyrite mineralization located on the Bass River at the Londonderry Fault. The occurrence consists of fine grained mineralization in the fault zone with a generally east-west trend (see Weeks, 1948; Donohoe and Wallace, in preparation).

Specular hematite is found at location M28 (Nova Scotia Department of Mines and Energy, Mineral Occurrence Number 11E/05-10) on a tributary of the Portapique River at the Rockland Brook Fault. The hematite is found in small veins adjacent and parallel to the fault.

South of M28 on the same tributary of the Portapique River is M29 (Nova Scotia Department of Mines and Energy, Mineral Occurrence Number 11E/05-11), a lead-copper occurrence. No data on the occurrence exists in the files of the Department. Neither this occurrence or the previous one (M28) has been confirmed in outcrop.

East of the Folly River, the Folly River Schist contains many layers of "iron formation" (A. Hudgins, personal communication, 1976; M. Cullen, personal communication, 1982). This lithology is composed of hematite and magnetite associated with thin calcareous layers in the exposures of the East Folly River. These layers define bedding at this locality and are not parallel to the SB_2 foliation. The diagram in Figure 5 is from this location. The extent of the "iron formation" is unclear because of the lack of outcrop and the uncertainty of the FB_2 structural geometry.

RELATIVE AND ABSOLUTE AGES

Superposition of Units

The three formations of the Bass River Complex have a simple outcrop pattern (Fig. 1) and apparently, relatively uncomplicated boundaries. The Great Village River Gneiss is always found in contact with the Gamble Brook Schist and never with the Folly River Schist. The contact between the Great Village River Gneiss and the Schist is congruent with the SB_2 foliation. Usually this is a moderate southerly dip. On Figure 2a this contact is obscured by the granite gneiss body of Rockland Brook. On Figure 2b the contact with the Gamble Brook Schist is folded into a synform by FB_3 folds. Generally the actual contact is not exposed; however, the contact is not gradational but sharp.

The contact of the Gamble Brook Schist and the Folly River Schist is moderately southerly dipping where observed. A typical contact between the two formations is shown in Figure 2a. The actual contact is an interleaving of quartzitic schist and fine grained grey to green chloritic schist. Quartzitic schists and quartzites also appear within the Folly River Schist. The origin of the interleaving at the contact and within the formation is not clear; it may be an original stratigraphic phenomenon or it may be due to structural "mixing" produced by large scale transposition of S_0 or thrusting during the DB_2 deformation.

Neither the Gamble Brook or the Folly River Schists have relict primary structures except bedding and therefore younging directions have not been observed. In developing the superposition of units without the aid of younging directions it has been necessary to examine the structural history of each unit more carefully.

In the mapping of the Bass River Complex it became apparent that the Great Village River Gneiss was more sturcturally complex. Relict metamorphic layering (Fig. 2) was found in the closures of FB_2 folds. No such earlier foliation was found in the other two formations. Instead mapping by myself and Peter Wallace and by M. Cullen (in preparation; Donohoe and Cullen, 1983) has shown that bedding can be found in the Gamble Brook and Folly River Schists. From these observations Donohoe and Cullen (1983) and Cullen (in preparation) have argued that the more complex deformation in the Great Village River Gneiss and the presence of bedding in the other formations is an indication that the Gneiss is older. The apparently simple and relatively uncomplicated boundary between the Gneiss and the Gamble Brook Schist and the structural argument above, support a superposition of Great Village River Gneiss (oldest), Gamble Brook Schist, and Folly River Schist.

Radiometric Ages

Radiometric dating has begun to decipher the absolute ages of rocks in the Cobequid Highlands (Donohoe and Wallace, in preparation; Stirling et al., in preparation; Donohoe et al., in preparation). In particular the dates on the Debert River pluton (Donohoe et al., in preparation) and the McCallum Settlement pluton (Cormier, 1980; Stirling et al., in preparation) have indicated a Late Hadrynian to Early Cambrian age for these plutons and thus a Precambrian age for the Bass River Complex. The McCallum Settlement pluton (C on Fig. 1) has a newly reported Rb/Sr whole rock age of 575 ± 22 Ma (^{87}Sr/^{86}Sr = 0.7065; Gaudette et al., 1983). Radiometric dating of the Debert River pluton (D on Fig. 1) using the Rb/Sr system indicates an age of 596 ± 70 Ma (Donohoe et al., in preparation). Both of these plutons cut across the DB_2 and DB_3 deformation structures in the Bass River Complex.

The minimum age of the Bass River Complex has been investigated by dating of the granite gneiss bodies. Four granite gneiss bodies in the Bass River Complex were dated by Rb/Sr whole rock method. The locations of these granite gneiss units are shown in Figure 1. The oldest age of 839 Ma was obtained from the granite gneiss on the Portapique River (E). Younger ages of 642 ± 15 Ma, 626 ± 22 Ma and 363 ± 12 Ma were obtained from granite gneiss bodies on the Rockland Brook (F), Great Village River (G), and Economy River (H), respectively.

The granitoid gneiss of the Great Village River Gneiss has yielded K/Ar ages of 398 ± 17 Ma from a biotite separate and 425 ± 17 Ma from a muscovite separate (Wanless et al., 1972; recalculated by Keppie and Smith, 1978). The locations of these dates are shown in Figure 1. These dates do not reflect the antiquity of the Bass River Complex and have almost certainly been affected by younger deformations (Acadian, Alleghenian-Hercynian) and/or by the thermal effects of the adjacent Pleasant Hills pluton.

Interpretation of Radiometric Ages

The radiometric age data in the Cobequid Highlands is from four granite gneiss bodies (E to H on Fig. 1) and from granitoid gneisses in the Mt. Thom Complex (described later). Field evidence indicates that the granite gneiss bodies were once granite plutons which had been emplaced into the sedimentary and volcanic envelope of the present day Gamble Brook and Folly River Schists. The plutons were strongly metamorphosed during DB_2 deformation and deformed twice (DB_2, DB_3). Much later during the Middle Paleozoic (?Carboniferous) these granite gneiss bodies have been subjected to cataclastic deformation during fault movement and thermal metamorphism during diabase dyke swarm emplacement.

The oldest radiometric date, 839 Ma from granite gneiss body E on Figure 1, represents a probable minimum age for the granite gneiss bodies as a whole. The data have been reset by metamorphism associated with the DB_2 deformation.

Three other granite gneiss bodies have yielded younger ages (F, G, H on Fig. 1). The first two dates are from granite gneiss bodies on Rockland Brook (F) and Great Village River (G) which have been intruded by diabase dyke swarm. The thermal effects have probably reset the dates on these two bodies. The granite gneiss body on the Economy River (H) has the youngest date. It is adjacent to major faults and intruded by the Pleasant Hills pluton (B) which has a whole rock and mineral Rb/Sr isochron of 315 ± 25 Ma (Cormier, 1979). The date has probably been reset by the thermal effects of the pluton and cataclasis accompanying the fault movements.

The Rb/Sr whole rock isochron of 839 Ma is helpful in establishing a minimum age for the deformation and metamorphism of the DB_2 event. If the correlation of the Great Village River Gneiss with the Mt. Thom Complex (discussed in Correlation) is reasonable then the Gneiss is older than ca. 930 Ma (Gaudette et al., 1983; Donohoe and Cullen, 1983).

Trends of the DB_3 deformation are crosscut by the McCallum Settlement Granite (C on Fig. 1) which has a Rb/Sr whole rock age of 575 ± 22 Ma. Thus the age of the DB_3 deformation cannot be fixed but floats between 840 Ma and 575 Ma.

CORRELATION

Recently, gneisses in the Saint John, New Brunswick region and in parts of the Cape Breton Highlands have been identified as probable or possible "basement" gneisses. Radiometric dating and geological mapping have indicated that these gneisses have old ages or are structurally and metamorphically more complex.

Cape Breton Highlands

Geological mapping by Barr et al. (1979) identified gneisses at Kellys Mountain on the Trans-Canada Highway which were lithologically dissimilar to the lithotypes in the Hadrynian or older George River Group in the same area. Keppie (1979) combined these gneisses on the new geological map of Nova Scotia with other unnamed gneissic units further north in the Highlands and termed them all part of the "basement complex". The basis for the separation from the George River Group is the lack of paragneiss, metasedimentary schists, or marbles.

The orthogneisses at Kellys Mountain on Cape Breton Island were dated by Olszewski et al. (1981) using the Rb/Sr system. Five whole rock samples yielded an age of 701 ± 66 Ma with an initial ratio of $^{87}Sr/^{86}Sr$ = 0.7056. The samples are from an area of high metamorphic grade and varying amounts of partially melting. Olszewski et al. (1981) and Jamieson (personal communication, 1982) interpreted the date as a metamorphic date.

Recent mapping in the central highlands area of Cape Breton by R. A. Jamieson of Dalhousie University (personal communication, 1982) has shown complex gneissic units which are lithologically distinct from the metasediments and marbles of the George River Group in the area. Typical George River Group lithotypes are intruded by the Baddeck Lakes Complex (mostly dioritic composition) in the southern central part of the Cape Breton Highlands. Jamieson dated the pluton by the Rb/Sr system at approximately 750 ± 65 Ma (personal communication, 1982). This date shows that the George River Group must be older than 750 Ma. Unconformable relations between the basement and the George River Group cover have not been observed.

Saint John, New Brunswick Region

The central part of Saint John city is underlain by structurally complex, high metamorphic grade gneisses. Currie et al. (1981), and Olszewski and Gaudette (1982) considered the gneisses to be older than the Green Head Group. The gneisses, named the Brookville Gneiss by Wardle (1978), are structurally more complex than the marbles and metasedimentary rocks of the Green Head Group. Wardle (1978) and Currie et al. (1981) distinguished between the two units lithologically because the Brookville has a generally tonalitic composition compared to the quartzites, marbles, and pelites of the Green Head. All of the workers believe that metamorphism, deformation(s), and intrusions affected the Brookville and Green Head prior to the deposition of the mainly volcanic rocks of the Late Hadrynian Coldbrook Group. Hoffman (1974) studied the stromatolites in the Green Head Group and suggested an approximate age for the stromatolites of Neohelikian (1000 to 1400 Ma). Stromatolite dating is not precise, but the date does agree with radiometric work by Olszewski and Gaudette (1982). The volcanic rocks of the Coldbrook Group were dated by Cormier (1969) using the Rb/Sr system. The rocks yielded a whole rock isochron of 776 Ma (date recalculated by Olszewski and Gaudette 1982).

Zircons in the Brookville Gneiss were dated by Olszewski and Gaudette (1982) and showed an initial age from the upper intercept of 1641 ± 60 Ma. They suggested that a two lead-loss event curve is compatible with the data resulting in lead-loss ages of 783 ± 40 Ma and 369 ± 45 Ma (Olszewski and Gaudette, 1982). A quartz diorite gneiss, which is considered part of the Brookville Gneiss by Wardle (1978) was dated by the U/Pb system using zircons. Olszewski and Gaudette (1982) reported an upper intercept age of 827 ± 40 Ma and a lower intercept of 333 ± 40 Ma. Samples from the quartz diorite gneiss and the Brookville Gneiss yielded a combined whole rock isochron of 771 ± 55 Ma.

Possible Correlations

In the Cobequid Highlands the Bass River Complex and the Mt. Thom Complex are very similar in their structural and metamorphic histories (Donohoe and Cullen, 1983; Donohoe and Wallace, 1980; in preparation). Gaudette et al. (1983) reported that the Mt. Thom Complex has yielded a whole rock Rb/Sr isochron of 934 ± 82 Ma, establishing it as the oldest dated rock unit in Nova Scotia. Although lithotypes are not exactly similar, the absence of recognizable metasedimentary and metavolcanic rocks in the Mt. Thom suggests a possible basement terrain in which the "cover" has been eroded and/or the "basement" is a now thoroughly homogenized (structurally and metamorphically) unit composed of various rocks. The Mt. Thom Complex consists mainly of orthogneiss of granitoid composition. Some exposures at the western end of the outcrop area appear to be possible paragneisses. None of these lithologies have any primary structures. Bedding or primary layering has yet to be found as it has in the Gamble Brook and Folly River Schists.

The Bass River Complex as a whole is older than 839 Ma and the Great Village River Gneiss is older yet because of the structural break recognized by Donohoe and Cullen (1983) and Cullen (in preparation). Most probably the Great Village River Gneiss is equivalent to the Mt. Thom Complex. Their deformational histories are similar (Donohoe and Wallace, 1980) and similar types of orthogneisses appear in each unit.

Table 2 shows a correlation between the Greenhead Group, Gamble Brook and Folly River Schists, and the George River Group. All units have quartzites and either calcareous metasediments or marbles. Primary features such as stromatolites and/or bedding are locally preserved. Radiometrically, the work by Olszewski and Gaudette (1982) indicated that the Green Head Group is older than 800 Ma. For the George River Group, Jamieson (personal communication, 1982) has shown that it must be older than the intruding 750 Ma Baddeck Lake Complex. In the Cobequid Highlands the Gamble Brook and Folly River Schists are older than the 839 Ma age for one of the granite gneiss bodies.

Correlation of "basement" gneisses of the Avalon Zone in the Maritimes is more difficult because lithologies are not uniform and the radiometric ages not precise. The concensus of opinion for the Saint John region suggests that the Brookville Gneiss is older than the Greenhead Group (Currie et al., 1981; Olszewski and Gaudette, 1982). These authors also suggest that the Brookville Gneiss may be in part derived from the Green Head during a younger metamorphic event (ca. 800 Ma). Wardle (1978) has argued that the gneiss is a high grade derivative of the Green Head.

Table 2. Correlation of Precambrian rock units and events in the Avalon Zone of the Maritimes.

	SAINT JOHN NEW BRUNSWICK	COBEQUID HIGHLANDS NOVA SCOTIA	CAPE BRETON ISLAND NOVA SCOTIA
~800 Ma —	D,M,I,f	D,M,I,f	D,?M,I,f
"cover"	Green Head Group	Folly River Schist Gamble Brook Schist	George River Group
~1 Ga? —	D,M,?I,u	D,M,I,u	?D,?M
"basement"	Brookville Gneiss (800 to 1640 Ma)	Great Village River Gneiss and Mt. Thom Complex (older than 930 Ma)	unnamed gneissic "basement" (Kellys Mt. Gneiss) (older than 701 Ma)

SYMBOLS

D: deformation
I: intrusion
M: metamorphism
f: fault boundary
u: unconformity

The gneissic rocks at Kellys Mountain described by Barr et al. (1979) are not correlated with the George River Group by the authors or Keppie (1979; personal communication, 1982). At the Kellys Mountain peninsula the gneiss is severely and multiply deformed and highly metamorphosed to the point of partial melting. The George River rocks are metasiltstones and metawackes.

The protolith for the Brookville Gneiss may be as old as 1640 Ma. In the Cobequid Highlands the Mt. Thom Complex is 930 Ma or older. By correlation with the Mt. Thom, the Great Village River Gneiss is of similar age. In Cape Breton, the only date on the gneiss at Kellys Mountain is 701 ± 66 Ma (Olszewski et al., 1981). No older ages as yet have been reported.

CONCLUSIONS

The new radiometric ages from the Cobequid Highlands (Gaudette et al., 1983) and the associated structural studies (Donohoe and Cullen, 1983; Cullen, in preparation) have allowed a better understanding of the basement rocks in northern Nova Scotia. The Bass River Complex is composed of two lithotectonic elements: the old basement of the Great Village River Gneiss which is correlated with the 934 Ma Mt. Thom Complex and the cover of metasediments and volcanic rocks of the Gamble Brook and Folly River Schists. One of the granite gneiss bodies in the Gamble Brook Schist has a radiometric age of 839 Ma thereby setting an upper age limit for the cover rocks. Basement and cover relationships between gneisses and metasediments are suggested for the Saint John, New Brunswick region by Currie et al. (1981) and Olszewski and Gaudette (1982). A similar situation is inferred for parts of northern Cape Breton Island (Barr et al., 1979; R. Jamieson, personal communication, 1982). With the exception of the dated gneiss complex of Kellys Mountain, which has been reset by younger events (Olszewski et al., 1981), the rocks identified as basement are older than 900 Ma. The metasedimentary cover rocks are older than 750 to 800 Ma. A significant intrusive event and deformation(s) took place around 800 Ma in Saint John, the Cobequid Highlands, and parts of the northern Cape Breton Highlands.

The Avalon Zone in the Maritimes has a basement which has been fractured and broken by Paleozoic and Mesozoic faulting but is present throughout the Maritimes. This basement consists of two lithotectonic units: an older (>900 Ma) gneissic basement and a younger (800 to 1000 Ma) cover of metasedimentary and metavolcanic rocks.

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AGE AND ORIGIN OF THE BASEMENT ROCKS, COBEQUID HIGHLANDS, NOVA SCOTIA*

H. E. Gaudette**, W. J. Olszewski, Jr.**,

and H. V. Donohoe, Jr.

The Mount Thom and Bass River Complexes are strongly deformed and metamorphosed rock units occurring in fault bounded blocks which are considered, based upon field relationships, to be the oldest rocks in the Cobequid Highlands. A new Rb/Sr whole rock age of 930 Ma for the granitoid gneisses of the Mt. Thom Complex firmly establishes its antiquity. Rocks of the Bass River Complex are dated indirectly by the age of granite gneisses interpreted to have intruded the Bass River rocks (Rb/Sr whole rock ages range: 810, 640 and 370 Ma). The younger ages are probably due to intense mylonitization adjacent to the major wrench faults, and thermal effects from a diabase dyke swarm. The McCallum Settlement granite also intruded the Bass River Complex. Its whole rock age of 595 Ma sets a minimum age for these rocks.

The Bass River Complex consists of an older, more deformed "basement" and a younger less deformed "cover" of quartzitic rocks and mafic schists. We correlate the "basement" part of the Bass River with the Mt. Thom Complex; the "cover" is somewhat younger. The older Bass River rocks and the Mt. Thom Complex are suggested to be part of a block of continental crust which was probably deformed circa 950 Ma. The younger "cover" was deposited and deformed somewhat later in the Precambrian.

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DEFORMATION, AGE, AND REGIONAL CORRELATION OF THE MT. THOM AND BASS RIVER COMPLEXES, COBEQUID HIGHLANDS, NOVA SCOTIA*

H. V. Donohoe, Jr., and M. Cullen**

The Mt. Thom Complex (eastern end) comprises various biotite-garnet gneisses, amphibolites, and granitoid gneisses. These rocks have been deformed at least three times. The first deformation foliation is seen only in the closures of rare second folds. The second deformation is the most pronounced and was accompanied by amphibolite facies metamorphism. Third generation folds deformed the second foliation. A whole rock Rb/Sr age from granitoid gneisses (930 Ma) sets a minimum age for the Complex. The Bass River Complex is exposed in an east-west fault block. It consists of an older "basement" of various gneisses and a younger "cover" of quartzites and mafic schists. The "basement" is deformed more than the cover. After deposition of the "cover" rocks and intrusions of granite (now granite gneiss) all rock units were subjected to intense L-S ductile strain and high amphibolite facies metamorphism of the second deformation and folding of the third deformation. The highest grade is spacially near the granite gneiss bodies. Whole rock Rb/Sr ages from the granite gneiss show the range of 810, 640, and 370 Ma. The oldest time sets a minimum age for the intrusion of the granite and possibly the onset of the second deformation. The younger ages have been modified by mylonitization due to faulting or the thermal effects from a diabase dyke swarm. The basement unit of the Bass River Complex is probably correlative of the Mt. Thom; both of these units have similarities to the unnamed basement in Cape Breton and the Brookville Gneiss in Saint John, New Brunswick.

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*Presented at the 1983 Geological Society of America, Northeastern Section Meeting, Kiamesha Lake, New York; Geological Society of America, Abstracts with Programs, 1983, v. 15, no. 3.

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EDUCATION AND PUBLIC AWARENESS PROGRAM

H. V. Donohoe, Jr.

The Mineral Resources Division of the Nova Scotia Department of Mines and Energy has a wealth of information about the geology and mineral resources of the Province. However, a large number of people either do not know about this information or do not understand it. The audience for our information generally has been scientists or technical people. The Department has defined a need for an education and public awareness program to supply nontechnical and easy to understand technical information to the general public and other government agencies.

The benefits of such a program are an increased awareness of the geology and mineral resources of the Province. The Department and the mining and exploraton industry will benefit by a better image. Hopefully this will mean a larger source of informed people and organizations in discussing such problems as mining, land use planning, and science education.

Over the last three decades the Department has produced a large number of pamphlets and general interest articles about the geology and mineral resources of the Province. These publications went out of print or were never updated so that at present there is very little nontechnical information. The Department has recognized this need and has begun to develop a program of pamphlets, maps, brochures, resource material for schools, and courses.

A course entitled "Prospecting and Geology in Nova Scotia" was offered during the fall term of 1982 through the Dalhousie University Part Time Studies and Extension Department. Support for the course has come from the Nova Scotia Department of Mines and Energy, Department of Geology of Dalhousie University, and the Chamber of Mineral Resources of Nova Scotia. The instructors are Howard Donohoe of Nova Scotia Department of Mines and Energy and Peter Wallace of Dalhousie University.

Other projects to be developed and completed over the next year are a geological history of Nova Scotia and a history of mining in the Province. The Department is working with the Nova Scotia Museum, the Atlantic Geoscience Society, and the Chamber of Mineral Resources of Nova Scotia to produce co-operatively, general interest publications.

THE STYLE AND HISTORY OF GLACIATIONS IN NOVA SCOTIA AND THEIR BEARING ON THE SEARCH FOR MINERAL DEPOSITS*

R. R. Stea

ABSTRACT

Sedimentation in Nova Scotia during the Quaternary was largely governed by the advance and retreat of continental and local ice masses. Most of the Nova Scotia landscape is a record of the last major ice advance in the Late Wisconsinan, although lowland regions preserved till sheets and recessional sediments dating back to the last interglacial period. Each region therefore requires a different approach to mineral exploration.

The area of the Paleozoic Meguma Terrane in southern mainland Nova Scotia is characterized by a relatively thin, locally derived gravel-rich till sheet or ground moraine broken by drumlin fields. The gravel-rich till sheet is an ideal exploration tool and simple models of glacier dispersal have been applied successfully to trace back potential ore sources. The drumlin fields however, can complicate exploration because of the thickness of tills (in excess of 20 m) and their stratigraphy. The upper drumlin till, for example, is largely allochthonous, composed of debris transported across the Meguma Terrane from the Carboniferous-Triassic sedimentary basins to the north.

The lowland regions of Nova Scotia represented by the Carboniferous-Triassic sedimentary basins are characterized by thick drift accumulations. More complex models of a glacier dispersal are required to explore successfully in these regions. Ice advances from different centres have affected the regions and are recorded with superimposed till sheets. Pleistocene mapping is a necessary adjunct to an exploration program in order to determine the sense of movement during these glacial stades. In order to trace back mechanically dispersed anomalies, a stratigraphic approach to detailed follow-up may be warranted. Some companies have employed reverse-circulation rotary drilling and auger techniques to sample through multiple-drift sequences.

Highland regions of Nova Scotia, such as the Cape Breton Highlands and Cobequid Highlands can be devoid of drift cover. Whether or not they were glaciated or covered with a thin protective carapace of ice is being debated. Geochemical exploration techniques in these regions can be similar to conventional techniques employed in nonglaciated terranes such as soil and stream sampling.

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*The Canadian Institute of Mining and Metallurgy Lecture Tour, November 1982; CIM Bulletin, in press.

TILL GEOCHEMISTRY OF THE MEGUMA TERRANE IN NOVA SCOTIA AND ITS METALLOGENIC IMPLICATIONS*

R. R. Stea

and

G. A. O'Reilly

ABSTRACT

Tills on the Meguma Terrane of Nova Scotia have distinct chemical signatures that relate primarily to their provenance and genesis. A gravel-rich till sheet covers most of the area and it is divisible into lithological facies derived from the following three major bedrock units in the area: granitic rocks, slate and metagreywacke. The till facies are characterized by a content of >90% locally derived clasts. Dispersal of these till facies onto adjacent rock types is in the order of 1-4 km. Within this range, the clay fraction (<2 µm) of these tills will exhibit strong anomaly to background contrast for most trace elements dispersed from a mineralized bedrock source. Slate till facies will tend to have anomalous values of Pb, Mo and Fe and depressed Cu, Ni, Co, Zn and Mn values down-ice from sulphide-bearing mineral deposits. This is probably due to weathering of the more mobile elements in the highly acidic and oxidizing environment of the pyritiferous slate till facies.

Red mud-rich till (Lawrencetown Till) is found mantling or forming drumlins in the region. The red mud and 10 and 30 per cent of the clast fraction are derived from sources 20 km to 70 km north of the Meguma Terrane. These "foreign" components can effectively dilute anomalies derived from local bedrock mineralization, and produce a till with homogeneous trace element distribution patterns.

Tin and W anomalies in sand-sized heavy mineral separates are commonly found in areas associated with granitic rocks. Tin anomalies predominate in the higher regional metamorphic zones of the Meguma Terrane, and composite Sn-W and W anomalies correspond to the lower regional metamorphic zones. Known Sn-W deposits associated with granitic rocks of the region also display a similar distribution. This implies a zonation of major mineral assemblages relative to the level of emplacement of the granitic rocks. Hercynian granitic terranes in Europe are known to display similar metal zonations related to depth of emplacement.

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*5th Symposium on Prospecting in Areas of Glaciated Terrain-1982; The Canadian Institute of Mining and Metallurgy, Geology Division, St. John's, Newfoundland, August 1982.

DISCOVERY OF MINERAL DEPOSITS OF THE MEGUMA TERRANE OF NOVA SCOTIA USING DRIFT PROSPECTING AND TILL GEOCHEMISTRY*

G. A. O'Reilly

ABSTRACT

Much of mainland Nova Scotia is extensively covered by glacial till. Geochemical survey and prospecting techniques using till are useful in detecting concealed bedrock mineralization. A nationwide renewed interest in gold exploration and recognition of the existence of deposits of Sn and related elements associated with the granitic rocks of mainland Nova Scotia have resulted in a boom in exploration of the southern and eastern mainland since 1975. This area, called the Meguma Terrane, forms a seaward sloping plain and is covered predominantly by a gravel-rich till sheet. This till sheet consists of three main facies: granite till, slate till and metagreywacke till. These till facies reflect the three main bedrock types which underlie most of the Meguma Terrane. Mapping has shown that a change in till facies reflects contacts of the main bedrock types. Therefore the local provenance of the gravel-rich till sheet indicates it is an excellent medium for till geochemical surveys and drift prospecting.

Most of the many gold producing districts found in the Meguma Terrane were discovered by some manner of boulder tracing. This prospecting proved successful in spite of a limited knowledge of the Pleistocene geology of the region by these prospectors. However, in the Blockhouse gold district in 1896, W. H. Prest panned sections of glacial drift and defined a three-dimensional dispersal fan of gold in the till. This fan was traced up ice to its source, a previously unknown fissure vein.

More recently regional till geochemical surveys by government agencies and exploration companies have been used successfully to outline anomalous values of elements known to be associated with mineralization occurring in the endocontact and exocontact zones of specialized or mineralized granitoids. At Wedgeport and East Kemptville in southern Nova Scotia, this type of mineralization occurs and the elemental assemblages described from the mineralized zones are reflected as down ice dispersion of anomalies of these same elements in the gravel-rich till sheet. Detailed follow-up geochemical till surveys and drift prospecting were used by Shell Canada Resources to discover and help outline the East Kemptville tin deposit which occurs in an area of little or no outcrop.

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*The Canadian Institute of Mining and Metallurgy Lecture Tour, November 1982; CIM Bulletin, in press.

SURFICIAL GEOLOGY OF THE WESTERN PART OF CUMBERLAND COUNTY, NOVA SCOTIA *

R. R. Stea

ABSTRACT

Surficial materials of the western part of Cumberland County, Nova Scotia were mapped in the summer of 1982. New information was gained on the glacial history of the region. At Joggins, Nova Scotia three tills were confirmed and studied in detail. An early eastward ice flow is indicated by 'old' striae and the lowest till at Joggins. Major southern to southwestern ice flows created the upper two tills at Joggins and produced, upon recession, large areas of stratified drift including stagnation moraine and outwash deltas. Emerged marine features along the coast of Chignecto Bay decrease in elevation from 37 m at Squally Point to 15 m at Joggins. The oldest, eastward flow may be Early Wisconsinan in age; the later pulses of southern to southwestern flowing ice are probably Middle to Late Wisconsinan in age.

INTRODUCTION

The mapping of surficial deposits in northern Nova Scotia is part of a project that also involves trace element analysis of till. This project is part of the Canada-Nova Scotia Co-operative Mineral Program 1981-4. It follows a program of surficial mapping and till geochemistry that was initiated by Canada Department of Regional Economic Expansion and the Nova Scotia Department of Mines in 1977 covering southern Nova Scotia on the Meguma Terrane (Stea and Fowler, 1979, 1981; Stea, 1982a; Stea and O'Reilly, 1982). The aim of this project is to provide a similar data base on the nature and extent of surficial materials and the effects of glaciation, in order to aid mineral exploration, environmental assessment, and industrial construction.

The area covered by this report lies between latitudes 45°15'N and 45°50'N and longitudes 64°20'W and 65°00'W, that is, west of Parrsboro and is a summary of field work carried out during the 1982 season.

Physiography and General Geology

The study area consists of two distinct physiographic regions; the Cumberland-Pictou lowland (Goldthwait, 1924) and the Cobequid Highlands. The lowland area is predominantly underlain by sedimentary rocks of the Cumberland Group (Late Carboniferous). The highland region which rims the southern and southwestern coast of the peninsula (Fig. 1) is formed by metasedimentary volcanic and igneous rocks of Hadrynian, Devono-Carboniferous, and Early Carboniferous age that are segregated into numerous fault blocks and bounded on the south by the Minas Geofracture (Donohoe and Wallace, 1978; Keppie, 1982).

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Contribution to Canada-Nova Scotia Co-operative Mineral Program 1981-84. Project carried by Geological Survey of Canada and Nova Scotia Department of Mines and Energy.

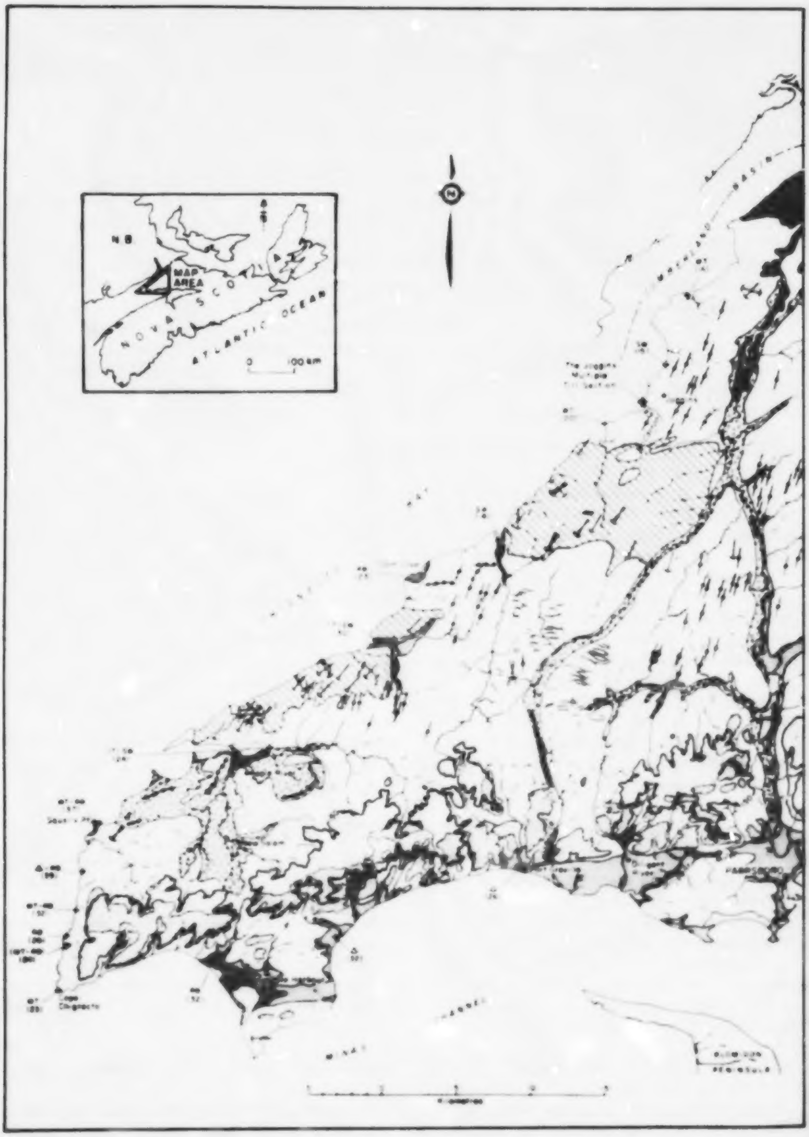

N B
MAP AREA
NOVA SCOTIA
ATLANTIC OCEAN
0 100 km
N
PARRSBORO
MINAS CHANNEL
Cape Chignecto

Figure 1. Surficial geology of the western part of Cumberland County, Nova Scotia (based in part on photogeological interpretation by D. R. Grant, 1982).

LEGEND

MARINE DEPOSITS

■ Recent marine deposits including saltmarsh, tidal channel and beach environments.

▩ Marine deposits of Postglacial time found above present day H. H. W. level, including sublittoral-littoral deposits (clay-silt-sand) and beach deposits (sand-gravel).

GLACIAL DEPOSITS

☐ Glaciolacustrine deposits: clay, silt, and sand forming flat plains.

☐ Outwash deltas: sand and gravel usually in the form of sediment aprons at valley mouths, fluvial topset beds sometimes overlying marine foresets and bottomsets in the classical 'Gilbert type' delta form.

░ Glaciofluvial (ice contact) deposits: silt, sand, gravel forming hummocky terrain and valley-side terraces.

☐ Till: undifferentiated, mainly reddish-brown, silt-clay matrix, polymictic; lodgement phase generally 2-3 m thick; locally overlain by gravel-rich till (ablation phase ?) forming morainal ridges and hummocky terrain.

BEDROCK

☐ Regolith: fragmented, unconsolidated rock weathered to various thicknesses depending on lithology.

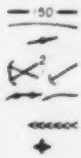
▨ Scoured bedrock: bedrock that is glacially scoured with a discontinuous veneer of till <1 m thick. Terrain is generally controlled by bedrock characterized by a series of strike ridges composed of more resistant sandstone bedrock.

Symbols

Contour of 150 m elevation
Geological boundary
Fluted and druMlinized terrain
Striae (ice flow direction known, unknown, numbers indicate relative age 1 being older.)
Morainal ridge (major, minor)

Esker (direction of flow assumed)

Stratigraphic section



Symbols for emerged marine features

Location ✛ WT geological feature that was measured i.e. wave-cut terrace.
(22) elevation in metres above mean sea level.

Features	
delta	△
upper limit sand wash	SW
raised beach	RB
wave-cut terrace	WT
limit of submergence	

Geology by R. R. Stea, 1982

Previous Work

Previous mapping done in the area has been of varying scale and purpose. Chalmers (1895) and Wickenden (1941) mapped the northern portion of the area. Swift and Borns (1967) and Wightman (1980) produced maps of the glaciofluvial and glaciomarine sediments on the Minas Basin shore. MacNeill (1956) and soil survey scientists (Nowland and MacDougall, 1973) produced maps of the area dealing with aspects of surficial geology.

Concomitant with the previous mapping was the development of glaciation concepts for the region. Chalmers (1895) noted two main sets of striations in the region, an earlier set trending eastward and later sets trending southward and southwestward. He attributed the eastward trending set to ice flowing eastward from New Brunswick which he called the Northumberland Glacier. Later southward and southwestward sets were attributed to a more or less separate ice mass centred on the isthmus of Chignecto, which he termed the Chignecto Glacier. Goldthwait (1924) dismissed the evidence for chronologically separate local ice masses and explained divergent striae in terms of a lobation of Laurentide ice which he called the 'Acadian Bay Lobe'. In recent years, Prest and Grant (1969) returned to the local ice concept. They stated: "It appears that the development of local ice in some parts of the region was sufficiently early and extensive to hold off the Laurentide ice flood or, at least, to direct it along defined channels." Grant (1977) further developed this model of restricted ice cover and depicted the limit of Late Wisconsinan glaciers. In his reconstruction the western Cobequid Highlands remained essentially ice-free during this period. Alternative viewpoint was put forward by Wightman (1980) in his study of pebble lithology of the outwash deltas of the northern shore of the Minas Basin. He concluded that at some time in the Late Wisconsinan, ice did cross part of the Cobequid Highlands.

The mapping of surficial deposits and ice flow features, and the detailed study of important stratigraphic sections which are the main aims of this project shed some new light on the nature and timing of glaciation in the region.

SURFICIAL UNITS

Glacially Scoured Bedrock

Areas along the Chignecto Bay coast of the study area are characterised by exposed bedrock with a discontinuous veneer of till and boulders. The topography is controlled by bedrock with strike ridges formed by relatively resistant sandstone units. The till is generally thin (<1 m), loose and rich in clasts consisting primarily of the adjacent bedrock. The surface of many of the exposures was scoured by glaciers that moved generally southwestward. Pebbles in the sandstone matrix reveal 'pressure shadows', or miniature crag-and-tail (Fig. 2). Many surfaces exhibit crossing striations with younger southwestward trending sets curving to conform to local topographic trends. Preserved on the lee side of some outcrops are relatively more weathered, more degraded striations that are oriented eastward and southeastward.

Figure 2. Pressure shadows or miniature crag-and-tail features on the down-glacier or lee side of quartzite pebbles embedded in a sandstone matrix near Apple River, Nova Scotia. The inferred azimuth of ice flow is 210°.

Regolith

The surface material of large areas in the Cobequid Highlands is bedrock that has been fragmented, disintegrated and altered to varying degrees in situ (Fig. 1). Mechanical and chemical weathering are implied. Hence, there is little or no evidence of glacial scouring in these regions. Till generally pinches out upslope against the friable rock and overlies it in some areas of the highlands. Bedrock lithology is evidently the controlling factor in the depth and intensity of rock weathering. Metamorphosed, steeply-dipping shales north of Advocate Harbour have been disrupted and disaggregated to depths of 10 m below the surface and foliated granites at Cape Chignecto are broken for only 3-5 m. The age and genesis of this material is problematic, but it must predate the overlying till.

TILL

The Joggins Till Section

At the mouth of McCarron Brook, north of Joggins, shore cliffs reveal three till units with a total thickness of 20 m. The section was first described by Wickenden (1941). Prest et al. (1972, p.37) noted that from bottom to top the three tills are distinctly reddish, grey and yellowish and attributed them all to fluctuations of the southward and southwestward flowing ice. The author's observations on the section are summarized in Figure 3.

The lowest till (Unit I) is characterised by reddish hues and a higher percentage of allochthonous clasts, particularily chloritised, foliated granitic clasts. Their provenance is uncertain but is likely to be New Brunswick. The fabric strikes east-west at the bottom of the unit and changes to northeast-southwest at the top. The till overlies a bedrock surface with striae oriented 110-290 degrees and are thus aligned with the till fabric. Unit Ic, below its contact with Unit II, shows signs of alteration. This may represent a period of subaerial weathering before deposition of the overlying till.

The upper tills (Units II and III) are characterized by a predominance of sedimentary clasts, mainly sandstone, limestone, and coal, and by a northeastward trending fabric. Unit III is differentiated from Unit II by a weathered appearance and numerous sand partings along fissility planes.

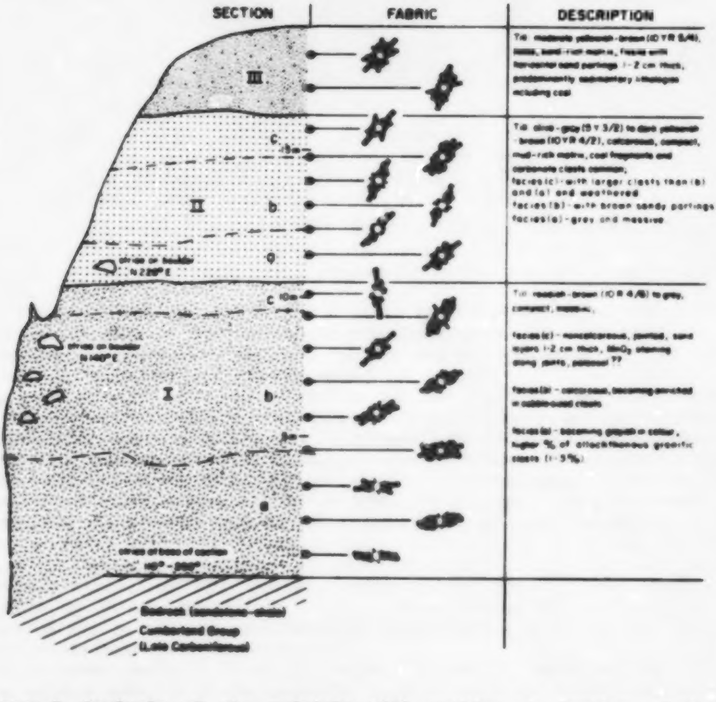

SECTION
FABRIC
DESCRIPTION
III
II
I
c
b
a
facies(c) - with larger clasts than (b) and (a) and weathered
facies(b) - with brown sandy partings
facies(a) - grey and massive

Figure 3. Analysis of the multiple till section at Joggins, Cumberland County, Nova Scotia.

Surface Till Sheet

Till covers a major part of Cumberland County north of the Cobequid Highlands. The most prevalent type is a reddish-brown, mud-rich till composed chiefly of sandstone clasts. It is generally 2-5 m thick and overlies bedrock surfaces inscribed with southwestward trending striae. A gravel-rich till phase is also present locally, and is associated with hummocky and ribbed moraine areas. In the Joggins area the surface till has a more greyish cast and is calcareous, presumably because of incorporated local grey limestones, carbonaceous shales and coaly beds.

GLACIOFLUVIAL SEDIMENTS

Ice Contact Stratified Drift

Large bodies of ice contact stratified drift in the form of kames, kame terraces and eskers occur in the region (Fig. 1), notably in the Apple River area, and the valleys of River Hebert, Kelley and Parrsboro rivers. Spectacular kame terraces (Fig. 4) are found along the Parrsboro River, associated with a recessional end moraine (Wightman, 1980). These deposits show rapid changes in grain sizes between beds and in some cases have intercalated flow tills (Nielsen, 1976, p. 47). The deposits can reach up to 30 m in thickness.

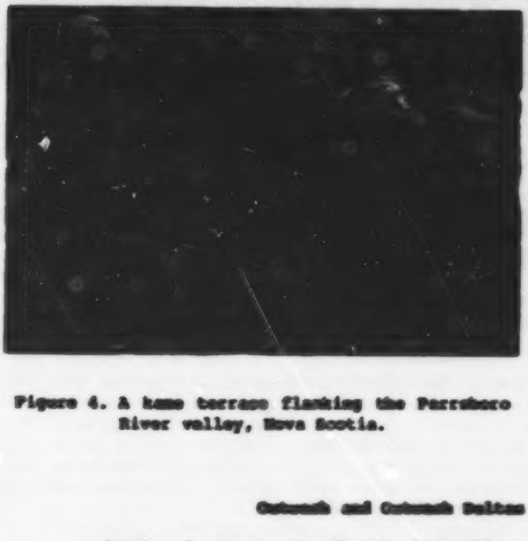


Figure 4. A kame terrace flanking the Parrsboro River valley, Nova Scotia.

The Apple River area is also characterised by ice contact deposits and moraines. D. R. Grant (personal communication, 1982) interprets this broad zone of ice frontal deposits to mark a major glacier marginal stand, perhaps the stadial limit.

Outwash and Outwash Deltas

South of the mouth of the Grenville, Diligent and Parrsboro rivers are flat plains, locally dissected, pitted, and terraced, composed of horizontal beds of gravelly sand. This unit has been termed the Saints Rest Member and is interpreted as outwash (Swift and Borns, 1967; Wightman, 1980). Where shoreline exposure reveals stratigraphy, the Saints Rest Member is found to overlie marine foreset and bottomset beds termed the Advocate Harbour Member (Swift and Borns, 1967) in the classic 'Gilbert delta' form (Wightman, 1980).

MARINE SEDIMENTS

Emergent Marine Features

At Advocate Harbour, the Saints Rest Member occurs inland from marine shoreline deposits (Swift and Borns, 1967). Raised strandlines occur in this area. The highest strandline west of Advocate Harbour was measured at 32 m above mean sea level. The outwash deltas and raised marine features along the southern coast are discussed in detail by Wightman (1980).

Along the coast from Cape Chignecto to Squally Point (Fig. 1) is a discontinuous wave-cut terrace in bedrock. At Squally Point this terrace has superimposed littoral-type deposits which attain an elevation of 37 m above mean sea level (Fig. 5). The terrace elevation apparently decreases from Squally Point to Cape Chignecto (23 m above mean sea level), but it may actually be a complex of several successive levels.

Figure 5. A wave-planed surface on bedrock at Squally Point, veneered with beach deposits that reach 37 m above mean sea level.

Along the Chignecto Bay coast raised marine deposits are best exposed at Clam Cove where gullying along a logging road reveals a transition from unaltered till, a beach berm with rounded stones, to upper shoreface marine sands. The height of the emerged strandline is 23 m above mean sea level. The elevation of emergent marine features decreases along the coast of Chignecto Bay from an elevation of 37 m above mean sea level at Squally Point to 15 m at Joggins (Fig. 1).

GLACIAL HISTORY AND CORRELATIONS

The oldest striae in the region trend east and southeast. The lowest till at Joggins overlies striated bedrock and has a fabric concordant to this trend. The chloritised hornblende-bearing, foliated granitic erratics in this till suggest a New Brunswick provenance. This movement appears to have been due east in an initial stage, then later southeastward. For this reason it is correlated with the East Milford Till of the Carboniferous lowlands of central Nova Scotia to the south, which was also deposited by southeastward flowing ice. It overlies peat beds of interstadial and interglacial rank (Stea and Hemsworth, 1979; Stea, 1982b). Chalmers (1895) invoked the New Brunswick-centred 'Northumberland Glacier' to explain these trends, and in New Brunswick this event was termed the "Caledonia Phase" by Rampton and Paradis (1981, p. 13), who gave it a Wisconsinan age because striations related to it are inscribed on a wave-planed rock bench which was elsewhere assigned a Sangamon age by Grant (1980).

The silt and sand between Units I and II at Joggins (Wickenden, 1941, p. 144) and the altered Unit Ic may attest to a period of ice withdrawal, subaerial exposure and climatic amelioration before the deposition of Unit II.

Striae and fluting in the region indicate a major intermediate period of south-southwestward flow (Fig. 1). Rampton and Paradis (1981) termed this south-southwestward flow the 'Chignecto Phase'. Inland, these ice flow features appear to swing to a more southward direction (Fig. 1). This suggests ice radiating from a centre lying to the north of the map area. Till Unit II at Joggins contains abundant coal derived from the northeast and has a strong northeast-southwest striking fabric implying that it was deposited by this flow. Unit III may represent a late fluctuation in this flow, or a melt-out phase of Unit II. Younger southwestward oriented striae along the Chignecto Bay coast point to an ice lobe in the Bay induced by late-stage drawdown.

The 'Chignecto Phase' probably postdates the Early Wisconsinan, but since it has not yet been dated directly its age can only be speculated to be Middle-Late Wisconsinan. There is some evidence that ice on the Cobequid Highlands to the east of the study area reactivated and flowed northward subsequent to this phase (Prest et al., 1972, p. 39). Rampton and Paradis (1981) described two iceflow phases after the Chignecto Phase. Stea (1982b) postulated two Late Wisconsinan till-forming events in central Nova Scotia.

The deltas along the Minas Basin Shore, though not dated directly, are assigned a Late Wisconsinan age because they belong to the same general phase of submergence in the Bay of Fundy which, farther west, has been dated between 13 000 and 14 000 years B.P. Wightman (1980) suggested that the deltas were formed during recession of glaciers that had crossed the Cobequid Highlands, whereas Grant (1977) associated them with the limit of Late Wisconsinan northern ice which he placed on the northern flank of the Highlands. The question remains unresolved because this study can adduce no evidence bearing on the extent of ice during any of the three phases.

In the Minas Basin the configuration of marine limit, and hence its interpretation, is controversial. The elevation of the upper reach of the paleoshore was taken by Swift and Borns (1967) and by Wightman (1980) to be the contact between the foreset beds (the Advocate Harbour Member) and the topset, supposedly fluvial beds (the Saints Rest Member). Prest (1970), on the other hand, considered the topset beds to be littoral and thus argued for greater, more extensive submergence. Both however show a decline of the paleoshore eastward up the Minas Basin. This is attributed to a tapering of the effective ice load toward the southeast by Wightman and Cooke (1978) and by Grant (1980), whereas Prest (1970, p. 710) invoked an ice lobe retreating eastward in the Basin.

In Chignecto Bay also, the pattern of marine limit, specifically its decrease up the Bay (Fig. 1), is incongruous with the ice load model. Since the axis of the Bay is parallel to the general trend of isobases and hence to the contours of ice load as inferred from the overall direction of glacier recession to the northwest, there should be little or no differential uplift along its length. The irregular decline in marine limit therefore points to a last-stage ice lobe lying north of Squally Point which delayed marine incursion and thus led to successively lower marine limits. Moreover, the decline of marine limit also southward from its maximum reach at Squally Point, where the Apple River end-moraine belt terminates, may represent a manifestation of the sloping water plane in contact with the ice lobe or differential isostatic uplift.

ACKNOWLEDGMENTS

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APPENDIX I

OPEN ASSESSMENT REPORTS FOR 1982

11D/13B 54-I-67(01) (434037)	Uranium, Big Indian Lake, Hants County, Nova Scotia. M.E.X. Explorations Limited (for A. Hudgins). Report on prospecting and ground radiometric surveys, by L. D. Rankin, January 1980. 14 pages; 3 maps (location, prospecting, geological).
11D/13B 54-I-76(01) (434067)	Uranium, Kehoe Hill, Hants County, Nova Scotia. M.E.X. Explorations Limited (for Shell Canada Resources Limited). Report on geology, radiometric prospecting and drilling, by L. D. Rankin, Janurary 1980. 45 pages; 4 maps (location; sample and drillhole location; geological); drillhole logs; drillhole sections; chemical analyses; assays.
11D/13D 54-H-80(02) (434356)	Uranium, Grand Lake, Halifax County, Nova Scotia. B. Seaton. Report on drilling, by J. E. Dewe, March 1980. 9 pages; 9 maps (location, drillhole location, geological); drillhole logs; drillhole sections; core assays.
11D/14A 07-H-51(01) (434068)	Base Metals, Musquodoboit Harbour, Halifax County, Nova Scotia. Noranda Exploration Company Limited. Report on geological survey and soil and well water geochemical surveys, by J. A. MacIntosh, September 1980. 7 pages; 16 maps (location; geological; geochemical); soil geochemical profiles.
11D/15A 21-H-67(17) (434016)	Gold, Tangier, Halifax County, Nova Scotia. Services Geotechniques Shickshocks Incorporated (for L. Blondeau). Report on trenching and sluicing of regolith for placer gold, by R. A. Marleau, February 1980. 6 pages; 4 maps (location; geological); structural cross section; assays.
11D/15A 51-H-86(01) (434098)	Tin, Spry Bay, Halifax County, Nova Scotia. Shell Canada Resources Limited. Report on geological, till and rock geochemical surveys, by P. E. Sinclair, G. MacGillivary and B. Needham, November 1980. 10 pages; 11 maps (location; geological; geochemical); tables, chemical analyses.
11D/15D 21-H-65(02) (434001)	Gold, Sheet Harbour, Halifax County, Nova Scotia. St. Joseph Explorations Limited. Report on geological survey, and organic bank, humus, stream sediment, lake sediment and rock geochemical surveys, by A. L. Sangster and O. Wowkodaw, October 1979. 7 pages; 16 maps (geological; geochemical).
11D/15D 21-H-65(03) (434019)	Gold, Sheet Harbour, Halifax County, Nova Scotia. St. Joseph Explorations Limited. Report on geological survey and soil, stream sediment and lake sediment geochemical surveys, by A. L. Sangster and O. Wowkodaw, October 1979. 7 pages; 16 maps (geological; geochemical); chemical analyses.

11D/16C 21-H-63(13) (434053)	Gold, Salmon River (Dufferin Mine), Halifax County, Nova Scotia. St. Joseph Explorations Limited. Preliminary report on IP survey, by J. Wright, July 1980. 1 page; 1 map (geophysical).
11D/16C 21-H-63(14) (434069)	Gold, Salmon River (Dufferin Mine), Halifax County, Nova Scotia. St. Joseph Explorations Limited. Report on IP survey, by J. L. Wright, August 1980. 2 pages; 1 map (geophysical); IP pseudo sections.
11D/16C 21-H-63(15) (434081)	Gold, Salmon River (Dufferin Mine), Halifax County, Nova Scotia. St. Joseph Explorations Limited. Report on soil geochemical survey, by W. P. Binney, October 1980. 4 pages; 4 maps (location; sample location; geochemical).
11E/01A 21-G-30(04) (434048)	Gold, Liscomb Mills, Guysborough County, Nova Scotia. Claymore Management Limited. Report on work proposal, by W. A. MacPherson, April 1979. 6 pages; 3 maps (location; geological; mine plans).
11E/01D 21-G-05(13) (434092)	Gold, Cochrane Hill, Guysborough County, Nova Scotia. Northumberland Mines Limited and Sander Geophysics Limited (for Atlantic Gold Mines Limited). Report on humus geochemical survey, and airborne magnetic and airborne VLF surveys, by E. Harrington, G. W. Sander and W. R. Archer, November 1980. 41 pages; 6 maps (location; geochemical; geophysical); VLF profiles; tables, chemical analyses.
11E/02B 21-H-74(02) (434070)	Gold, Wire Lake, Halifax County, Nova Scotia. St. Joseph Explorations Limited. Report on IP surveys, by J. L. Wright, August 1980. 5 pages; 4 maps (geophysical); IP pseudo sections.
11E/02B 21-H-74(03) (434099)	Gold, Wire Lake, Halifax County, Nova Scotia. St. Joseph Explorations Limited. Report on geological and soil geochemical surveys and pit sampling, by W. P. Binney, December 1980. 5 pages; 16 maps (location; geological; geochemical).
11E/02C 07-H-05(02) (434011)	Base Metals, Bog Island Lake, Halifax County, Nova Scotia. Esso Resources Canada Limited. Report on geological survey, soil, rock and heavy mineral geochemical surveys, and drilling, by J. L. MacLeod, January 1980. 21 pages; 9 maps (geological; geochemical); drillhole logs; drillhole sections; core assays.
11E/03A 07-H-87(01) (434100)	Base Metals, Newcomb Corner, Halifax County, Nova Scotia. Shell Canada Resources Limited. Report on geology, till and rock geochemical surveys, pit sampling and overburden drilling, by R. A. Cornish, December 1980. 109 pages; 2 maps (location; geological/geochemical); drillhole logs; drill core analyses.

11E/03A 41-I-68(01) (434052)	Silica, Elmsvale, Hants County, Nova Scotia. L. E. Shaw Limited. Report on drilling, by R. F. MacAusland, July 1980. 28 pages; 1 map (location); drillhole logs.
11E/03B 21-D-21(05) (434082)	Gold, Gays River, Colchester County, Nova Scotia. N. Gass. Report on drilling, by N. Gass, October 1980. 11 pages; 2 maps (location; drillhole location); drillhole logs; assays.
11E/03D 06-D-34(15) (434063)	Barite, Middle Stewiacke, Colchester County, Nova Scotia. Terra Nova Explorations Limited. Report on geological survey and gravity interpretations, by D. E. McBride, June 1980. 4 pages; 4 maps (location; geological; geophysical).
11E/04A 41-I-62(01) (434026)	Silica, Nine Mile River, Hants County, Nova Scotia. L. E. Shaw Limited. Statement of expenditures, May 1980. 3 pages; 1 map (location).
11E/04A 54-I-41(01) (434101)	Uranium, Roulston Corner, Hants County, Nova Scotia. Saarberg Interplan Canada Limited. Report on geological survey, well water, stream sediment, soil and radon geochemical surveys, ground VLF, ground magnetic and ground radiometric surveys, by H. Quarch, K. Rikeit, R. J. Ryan and G. Adams, December 1980. 14 pages; 11 maps (location; geological; geochemical/geophysical); VLF profiles.
11E/05A 07-I-29(01) (434071)	Base Metals, Noel Lake, Hants County, Nova Scotia. Shell Canada Resources Limited. Report on geology and overburden drillng, by R. A. Cornish, September 1980. 28 pages; 2 maps (geological); drillhole logs; drill core chemical analyses; stratigraphic section.
11E/05A 07-I-29(02) (434103)	Base Metals, Noel Lake, Hants County, Nova Scotia. Shell Canada Resources Limited. Report on geological survey, till and rock geochemical surveys, pit sampling and overburden drilling, by R. A. Cornish, December 1980. 125 pages; 2 maps (location; geological/geochemical); stratigraphic charts and sections; drillhole logs; drill core analyses.
11E/05B 07-I-49(02) (434104)	Base Metals, Tennycape, Hants County, Nova Scotia. Gulf Minerals Canada Limited. Report on geological and soil geochemical surveys, by R. T. Boyd, December 1980. 64 pages; 8 maps (location; geochemical); stratigraphic charts; tables, chemical analyses.
11E/05C 06-D-01(03) (434000)	Barite, Bass River, Colchester County, Nova Scotia. N.E.X. Explorations Limited. Report on geological survey, by A. D. Hudgins, December 1979. 3 pages; 2 maps (location; geological).

11E/05D 07-D-33(06) (434017)	Base Metals, Londonderry, Colchester County, Nova Scotia. Preuvier Mines Limited. Report on soil geochemical survey, ground magnetic survey and drilling, by D. L. Black, March 1980. 7 pages; 6 maps, (location; drillhole location; geochemical; geophysical); drillhole logs; core assays.
11E/05D 07-D-33(07) (434031)	Base Metals, Londonderry, Colchester County, Nova Scotia. Preuvier Mines Limited. Report on prospecting and soil and stream sediment geochemical surveys, by D. L. Black, May 1980. 4 pages; 2 maps (location; geochemical).
11E/06B 07-I-45(01) (434105)	Base Metals, South Maitland, Hants County, Nova Scotia. Shell Canada Resources Limited. Report on geological survey, till and rock geochemical surveys, pit sampling and overburden drilling, by R. A. Cornish, December 1980. 114 pages; 2 maps (location; geological/geochemical); stratigraphic charts and sections; drillhole logs; tables, chemical analyses.
11E/08A 21-G-05(01) (434093)	Gold, Cochrane Hill, Guysborough County, Nova Scotia. Northumberland Mines Limited and Sander Geophysics Limited (for Atlantic Gold Mines Limited). Report on humus geochemical survey, and airborne magnetic and airborne VLF surveys, by E. Harrington, G. W. Sander and W. R. Archer, November 1980. 36 pages; 6 maps (location; geochemical; geophysical); VLF profiles; tables, chemical analyses.
11E/09D 07-B-12(01) (434083)	Base Metals, Doctors Brook, Antigonish County, Nova Scotia. Noranda Exploration Company Limited. Report on geological, ground radiometric and stream sediment geochemical surveys, by G. D. Graves, October 1980. 6 pages; 7 maps (location; geological; geochemical).
11E/10A 07-M-39(04) (434084)	Base Metals, Kirkmount, Pictou County, Nova Scotia. St. Joseph Explorations Limited. Report on drilling, by A. L. Sangster, September 1980. 11 pages; drillhole logs; sludge analyses.
11E/10A 54-M-19(01) (434012)	Uranium, New Glasgow, Pictou County, Nova Scotia. Noranda Exploration Company Limited. Report on geological survey, stream sediment and well water geochemical surveys, and ground radiometric survey, by M. W. Leahey, February 1980. 8 pages; 6 maps (location; geological; geochemical; geophysical).
11E/11A 54-D-70(01) (434056)	Uranium, North Earltown, Colchester County, Nova Scotia. Cominco Limited (for Cominco and Wyoming Mineral Corporation). Report on geological survey, alpha cup survey, ground VLF and ground magnetic surveys, by R. H. Randell, May 1980. 8 pages; 9 maps (location; drillhole location; geological; geophysical); histograms.

11E/11A 54-D-70(02) (434160)	Uranium, North Earltown, Colchester County, Nova Scotia. Cominco Limited (for Cominco and Wyoming Mineral Corporation). Report on geological survey, ground VLF and ground magnetic surveys, by R. N. Randell, July 1980. 3 pages; 6 maps (location; drillhole location; geological; geophysical); gamma ray logs; density logs; drillhole sections.
11E/11C 54-D-45(16) (434061)	Uranium, Tatamagouche, Colchester County, Nova Scotia. Cominco Limited. Report on geological survey, soil, rock, well water and stream sediment geochemical surveys and ground radiometric survey, by R. N. Randell, July 1980. 8 pages; 5 maps (location; geological; geochemical; geophysical).
11E/11D 54-D-71(01) (434059)	Uranium, Keble, Colchester County, Nova Scotia. Cominco Limited. Report on geological survey, soil, rock, well water and stream sediment geochemical surveys and ground radiometric survey, by R. N. Randell, July 1980. 9 pages; 4 maps (location; geological; geochemical; geophysical).
11E/12A 54-E-64(03) (434033)	Uranium, Westchester, Cumberland County, Nova Scotia. Cominco Limited. Report on drilling, by R. N. Randell, May 1980. 4 pages; 1 map (drillhole location); drillhole logs, drillhole sections; gamma ray logs.
11E/12A 54-E-64(04) (434034)	Uranium, Westchester, Cumberland County, Nova Scotia. Cominco Limited. Report on drilling, by R. N. Randell May 1980. 3 pages; 1 map (drillhole location); drillhole logs; drillhole sections; gamma ray logs.
11E/12A 54-E-64(05) (434035)	Uranium, Westchester, Cumberland County, Nova Scotia. Cominco Limited. Report on drilling, by R. N. Randell, May 1980. 2 pages; 1 map (drillhole loction); drillhole log; drillhole sections; gamma ray logs.
11E/12A 54-E-64(06) (434055)	Uranium, Westchester, Cumberland County, Nova Scotia. Cominco Limited (for Cominco and Wyoming Mineral Corporation). Report on geological and ground radiometric surveys and drilling, by R. N. Randell, May 1980. 5 pages; 4 maps (location; drillhole location; geological; geophysical); drillhole sections; gamma ray logs.
11E/12B 54-D-64(04) (434007)	Uranium, Cobequid Mountains, Colchester County, Nova Scotia. Gulf Minerals Canada Limited. Report on soil geochemical survey, by N. E. Downey, January 1980. 3 pages; 6 maps (geochemical).
11E/12B 54-E-65(01) (434036)	Uranium, Williamsdale East, Cumberland County, Nova Scotia. Cominco Limited. Report on drilling, by R. N. Randell, May 1980. 3 pages; 1 map (drillhole location); drillhole logs; drillhole sections; gamma ray logs.

11E/12C 10-E-23(01) (434359)	Coal, Oxford, Cumberland County, Nova Scotia. BP Canada Limited. Report on proposed coal exploration program, March 1981. 23 pages; 3 maps (location; drillhole location).
11E/12C 10-E-23(02) (434358)	Coal, Oxford, Cumberland County, Nova Scotia. BP Canada Limited. Report on stratigraphy, geology, trenching and drilling, December 1981. 92 pages; 4 maps (location; drillhole location; geological); drillhole logs; drillhole sections; gamma ray logs; caliper logs, SP logs; resistivity logs; neutron logs; deviation logs; density logs; stratigraphic cross section; structural cross sections; correlation diagrams.
11F/03C 54-G-24(03) (434107)	Uranium, Larrys River, Guysborough County, Nova Scotia. St. Joseph Explorations Limited. Report on geological, soil geochemical, ground VLF and ground radiometric surveys, by W. P. Binney, November 1980. 5 pages; 22 maps (location; geological; geochemical; geophysical); VLF profiles.
11F/05B 21-G-07(12) (434054)	Gold, Country Harbour, Guysborough County, Nova Scotia. Sander Geophysics Limited (for Paragon Explorations Limited). Report on airborne magnetic survey, by G. W. Sander and W. R. Archer, June 1980. 20 pages; 3 maps (location; geophysical).
11F/05B 21-G-13(13) (434061)	Gold, Forest Hill (Mile Lake), Guysborough County, Nova Scotia. International Geochemical Associates Limited (for International Geochemical Associates Limited and A. Hudgins). Reports on history of past production, stripping, trenching and humus and till geochemical surveys, by T. R. Clarke, July 1980. 29 pages; 2 maps (location; geochemical); structural cross section; bulk sample assays.
11F/06A 07-G-59(02) (434072)	Base Metals, Hazel Hill, Guysborough County, Nova Scotia. St. Joseph Explorations Limited. Report on basal till drilling program, by J. Hofer, May 1980. 10 pages; 4 maps (location; sample location; sample depth; surface contour); tables, drilling depths.
11F/06A 07-G-59(03) (434073)	Base Metals, Hazel Hill, Guysborough County, Nova Scotia. St. Joseph Explorations Limited. Report on till heavy minerals survey and heavy minerals geochemical survey, by St. Joseph Explorations Limited, September 1980. 28 pages; 3 maps (sample location; geochemical); till geochemical and heavy minerals profiles; tables, till heavy minerals; chemical analyses.
11F/06A 07-G-59(04) (434074)	Base Metals, Hazel Hill, Guysborough County, Nova Scotia. St. Joseph Explorations Limited. Report on preliminary interpretation of basal till heavy minerals geochemical data, by R. Jackson, September 1980. 15 pages; 2 maps (sample location; heavy minerals distribution); till geochemical heavy minerals profiles.

11F/10C 42-O-21(02) (434376)	Salt, St. Peters, Richmond County, Nova Scotia. Domtar Limited. Seaview No. 2 drillhole log, by T. E. Rowbottom, May 1968. 33 pages.
11F/10D 07-O-63(02) (434108)	Base Metals, St. Esprit, Richmond County, Nova Scotia. Duval International Corporation. Report on geological survey, soil and rock geochemical surveys, ground magnetic and ground EM surveys, trenching and drilling, by L. Stephenson, November 1980. 9 pages; 2 maps (location; geological); tables, chemical analyses; drillhole logs; magnetic profiles; EM profiles.
11F/11B 07-G-58(02) (434095)	Base Metals, Goose Harbour Lake, Guysborough County, Nova Scotia. Teck Explorations Limited (for Teck Corporation and Noranda Exploration Company Limited). Report on geological survey, and soil and rock geochemical surveys, by S. C. Godfrey, November 1980. 57 pages; 10 maps (location; geological; geochemical); photographs; stereonets; stratigraphic sections; tables, chemical analyses; soil profiles; histograms; cross sections.
11F/11B 42-O-30(21) (434377)	Salt, Port Richmond, Richmond County, Nova Scotia. Dow Chemical Comany. Report on drilling, geological interpretations and a comparison with the Pugwash Mine, by W. T. Haenggi, March 1971. 16 pages; 4 maps (geological; mine plans; drillhole location; geophysical); reserve estimates; structural cross sections; stratigraphic cross sections.
11F/14B 42-J-80(01) (434357)	Salt, Kingsville, Inverness County, Nova Scotia. Domtar Limited. Report on drilling, by C. Rene and T. E. Rowbotton, July 1968 to December 1969. 503 pages; drillhole logs; core assays.
11F/14B 42-J-80(02) (434375)	Salt, Kingsville, Inverness County, Nova Scotia. Domtar Chemicals Limited. Drillhole logs, by C. Rene, May to August 1970. 229 pages; core assays.
11F/14D 40-J-77(03) (434014)	Potash, Ashfield, Inverness County, Nova Scotia. Fundy Geoservices Limited (for Noranda Exploration Company Limited). Review of existing geology, stratigraphy, gravity and aeromagnetic data on the Ashfield potash prospect; and a report on new residual gravity models and bromine analyses of halites from drill core, by Fundy Geoservices Limited, February 1980. 25 pages; 4 maps (location; geophysical); gravity profiles; stratigraphic correlation charts; drillhole logs; bromine logs; core analyses; structural cross sections; drillhole sections.
11F/14D 40-J-77(04) (434109)	Potash, Ashfield, Inverness County, Nova Scotia. Noranda Exploration Company Limited. Report on drilling, by P. Cooper, December 1980. 187 pages; 1 map (drillhole location); drillhole logs; gamma ray logs; density logs; caliper logs; neutron logs; sonic logs; tables, chemical analyses.

11F/16A 34-C-41(03) (434351)	Molybdenum, Gabarus, Cape Breton County, Nova Scotia. Louisbourg Mines Limited. Drill core analyses, August 1974. 17 pages; 2 maps (location; drillhole location).
11F/16B 27-C-07(05) (434040)	Lead, Big Glen, Cape Breton County, Nova Scotia. U. S. Borax Exploration (for Pacific Coast Mines). Report on geological and soil geochemical surveys and drilling, by W. B. Burton, April 1980. 4 pages; 5 maps (location; drillhole location; geological; geochemical; isopach, structural); drillhole logs; structural cross sections.
11F/16B 27-C-83(05) (434378)	Lead, Silver Mine, Cape Breton County, Nova Scotia. Phelps Dodge Corporation of Canada Limited. Report on IP survey, by R. A. Geisler, January 1963. 40 pages; 1 map (location); resistivity profiles.
11F/16B 27-C-83(06) (434379)	Lead, Silver Mine, Cape Breton County, Nova Scotia. Phelps Dodge Corporation of Canada Limited. Report on feasibility study based on milling 5000 tons per day, by W. A. Hutchison and D. A. Firth, May 1963. 51 pages; 1 map (mine plan); tables, expenditures; mine cross sections.
11F/16B 27-C-83(07) (434380)	Lead, Silver Mine, Cape Breton County, Nova Scotia. Phelps Dodge Corporation of Canada Limited. Report on drilling results, by I. M. Watson, May 1963. 20 pages; 17 maps (isopachs; contours, per cent lead; contours, grade; drillhole location); stratigraphic charts; drill core chemical analyses.
11F/16B 27-C-83(08) (434381)	Lead, Silver Mine, Cape Breton County, Nova Scotia. Phelps Dodge Corporation of Canada Limited. Report on preliminary feasibility study, July 1963. 30 pages; tables, expenditures; tables, ore reserve calculations; tables, production.
11F/16B 27-C-83(09) (434382)	Lead, Silver Mine Cape Breton County, Nova Scotia. Phelps Dodge Corporation of Canada Limited. Summary report on topographic, geological, soil and stream sediment geochemical surveys, ground magnetic, and IP surveys, water level testing and drilling, by R. K. Mudford, January 1964. 49 pages; stratigraphic charts; tables, chemical analyses; drill core chemical analyses.
11F/16B 27-C-83(10) (434383)	Lead, Silver Mine, Cape Breton County, Nova Scotia. Phelps Dodge Corporation of Canada Limited. Summary report on geological survey and stream sediment and soil geochemical surveys, by I. M. Watson, January 1964. 15 pages.
11F/16B 27-C-83(11) (434384)	Lead, Silver Mine, Cape Breton County, Nova Scotia. Phelps Dodge Corporation of Canada Limited. Report on feasibility study based on milling 2000 tons per day, February 1964. 19 pages; tables, expenditures; tables, ore reserve calculations.

11F/16B 27-C-83(12) (434385)	Lead, Silver Mine, Cape Breton County, Nova Scotia. Phelps Dodge Corporation of Canada Limited. Report on feasibility study of open pit mining (1000 tons per day, 1% cutoff), by H. E. Stuart, March 1964. 43 pages; 1 map (location); tables, expenditures; tables, ore reserve caluclations.
11F/16B 27-C-83(13) (434386)	Lead, Silver Mine, Cape Breton County, Nova Scotia. Phelps Dodge Corporation of Canada Limited. Report on feasibility study of underground mining (1000 tons per day, 3% cutoff), by W. A. Hutchison and D. A. Firth, March 1964. 29 pages; tables, expenditures; tables, ore reserve calculations.
11F/16B 27-C-83(14) (434387)	Lead, Silver Mine, Cape Breton County, Nova Scotia. Phelps Dodge Corporation of Canada Limited. Report on feasibility study of underground mining (2000 tons per day, 3% cutoff), March 1964. 17 pages; tables, expenditures; tables, ore reserve calculations.
11F/16B 27-C-83(15) (434388)	Lead, Silver Mine, Cape Breton County, Nova Scotia. Phelps Dodge Corporation of Canada Limited. Report on feasibility study of open pit mining (2000 tons per day, 1% cutoff), March 1964. 17 pages; tables, expenditures; tables, ore reserve calculations.
11F/16B 27-C-83(16) (434389)	Lead, Silver Mine, Cape Breton County, Nova Scotia. Phelps Dodge Corporation of Canada Limited. Report on feasibility study of underground mining (1000 tons per day, 4% cutoff), by W. A. Hutchison and D. A. Firth, June 1964. 64 pages; tables, expenditures; tables, chemical analyses.
11F/16B 27-C-83(17) (434390)	Lead, Silver Mine, Cape Breton County, Nova Scotia. James, Buffam and Cooper Consultants and Kilborn Engineering Limited (for Phelps Dodge Corporation of Canada Limited). Report on feasibility study of underground mining (5000 tons per day), by W. F. James and W. J. Fenton, October 1966. 49 pages; tables, ore reserves; tables, expenditures; flow chart, milling.
11F/16C 07-C-102(01) (434085)	Base Metals, Gillis Mountain, Cape Breton County, Nova Scotia. Noranda Exploration Company Limited. Report on soil and stream sediment geochemical surveys, by G. D. Graves, October 1980. 10 pages; 13 maps (location; geochemical).
11F/16D 07-C-31(04) (434350)	Base Metals, Deep Cove, Cape Breton County, Nova Scotia. L. J. Manning and Associates Limited (for Louisbourg Mines Limited). Compilation report on property history, geology, past drilling and recommendations, by J. W. Hogan, February 1975. 29 pages; 2 maps (location); drillhole sections; chemical analyses.

11F/16D 07-C-31(05) (434352)	Base Metals, Deep Cove, Cape Breton County, Nova Scotia. E. A. Hart Limited (for Louisbourg Property Holdings Limited). Evaluation report and past drilling results, by E. A. Hart, April 1978. 10 pages; 3 maps (location; geological); base metal contour plans.
11F/16D 07-C-31(06) (434353)	Base Metals, Deep Cove, Cape Breton County, Nova Scotia. Louisbourg Property Holdings Limited. Report on ground magnetotellurics, ground tellurics and ground EM surveys, August 1978. 7 pages; 1 map (location); tellurics profiles; pseudo depth plots; magnetotellurics profiles; EM profiles.
11F/16D 07-C-31(07) (434354)	Base Metals, Deep Cove, Cape Breton County, Nova Scotia. E. A. Hart Limited (for Louisbourg Property Holdings Limited). Report on drilling results and recommendations, by E. A. Hart, August 1979. 4 pages.
11F/16D 07-C-31(08) (434027)	Base Metals, Deep Cove, Cape Breton County, Nova Scotia. Louisbourg Property Holdings Limited. Report on geological survey, ground magnetic survey, trenching and drilling, by D. Forgeron, May 1980. 66 pages; 4 maps (location; geological); drillhole logs; geochemical profiles; core assays; chemical analyses.
11K/02A 54-C-103(01) (434096)	Uranium, Indian Brook, Cape Breton County, Nova Scotia. Uranerz Exploration and Mining Limited. Report on geological, rock geochemical and ground radiometric surveys, by S. Cheve, October 1980. 15 pages; 6 maps (location; geological; geochemical; geophysical); stratigraphic charts; cross sections; tables, chemical analyses; metallogenic models.
11K/02C 07-Q-12(02) (434020)	Base Metals, Middle River, Victoria County, Nova Scotia. Esso Resources Canada Limited. Report on geological survey and soil and heavy minerals geochemical surveys, by J. L. MacLeod, January 1980. 17 pages; 9 maps (location; geological; geochemical).
11K/02C 54-Q-46(01) (434097)	Uranium, Peters Brook, Victoria County, Nova Scotia. Uranerz Exploration and Mining Limited. Report on geological survey, rock and stream sediment geochemical surveys and ground radiometric survey, by S. Cheve, November 1980. 15 pages; 3 maps (location; geological; geochemical; geophysical); stratigraphic charts; frequency distribution diagrams; tables, chemical analyses.
11K/03D 07-J-78(01) (434015)	Base Metals, Loch Ban, Inverness County, Nova Scotia. Esso Resources Canada Limited. Report on geological survey and soil geochemical survey, by J. L. MacLeod, January 1980. 12 pages; 5 maps (location; geological; geochemical).

11K/07B 07-J-86(02) (434110)	Base Metals, Ryan Brook, Inverness County, Nova Scotia. Duval International Corporation. Report on geology, soil and rock geochemical surveys, ground EM survey and trenching, by P. Hibbins, November 1980. 16 pages; 4 maps (location; geological; geochemical; trench plans); trench profiles; EM profiles.
11K/07B 07-Q-24(03) (434111)	Base Metals, Savach Brook, Victoria County, Nova Scotia. St. Joseph Explorations Company Limited. Report on geological survey, soil and rock geochemical surveys and ground VLF surveys, by A. L. Sangster, October 1980. 8 pages; 12 maps (location; geological; geochemical; geophysical); VLF profiles.
11K/07B 07-Q-45(01) (434075)	Base Metals, Fortune Brook, Victoria County, Nova Scotia. Duval International Corporation. Report on geological, soil and stream sediment geochemical surveys, ground magnetic and ground VLF surveys, by P. Hibbins, September 1980. 9 pages; 5 maps (geological; geochemical; geophysical); chemical analyses (chip samples).
11K/07B 54-J-76(02) (434002)	Uranium, North East Margaree River, Inverness County, Nova Scotia. Lacana Mining Corporation. Report on geological survey, soil, rock, stream sediment and stream water geochemical surveys, and ground magnetic survey, by R. F. Weicker, November 1979. 44 pages; 7 maps (location; geological; geochemical; geophysical); histograms; chemical analyses.
11K/10B 07-J-09(49) (434029)	Base Metals, Cheticamp, Inverness County, Nova Scotia. Amax Minerals Exploration Limited. Report on soil, stream sediment and heavy minerals geochemical surveys, ground EM, ground IP and ground magnetic surveys, and drilling, by G. Covey, May 1980. 73 pages; 31 maps (location; geochemical, geophysical); drillhole logs; core assays; resistivity logs; IP logs; EM profiles; structural cross sections; chemical analyses.
20O/16A 51-R-33(02) (434086)	Tin, Plymouth, Yarmouth County, Nova Scotia. Shell Canada Resources Limited. Report on till geochemical survey, ground magnetic, ground IP, ground radiometric surveys and drilling, by P. K. Sarkar, June 1980. 37 pages; 6 maps (compilation; geochemical; geophysical); drillhole logs; drillhole sections; drill core chemical analyses; IP profiles; magnetic profiles.
20P/13C 54-R-29(02) (434087)	Uranium, Peter Lake, Yarmouth County, Nova Scotia. Can-Lake Explorations Limited (for E and B Explorations Limited). Report on geological survey, radon and soil geochemical surveys, ground radiometric and ground VLF surveys, by M. G. B. Palmer, May 1980. 52 pages; 7 maps (location; geological; geochemical; geophysical); chemical analyses.

20P/13C 54-R-29(03) (434171)	Uranium, Peter Lake, Yarmouth County, Nova Scotia. Can-Lake Explorations Limited (for E and B Explorations Limited). Report on soil geochemical survey and ground radiometric survey; and a report on a proposal and budget for tin exploration, by M. G. B. Palmer, January 1981. 29 pages, 4 maps (location; geochemical; geophysical); chemical analyses.
20P/15C 51-N-17(01) (434185)	Tin, Port Mouton, Queens County, Nova Scotia. Esso Resources Canada Limited. Report on geological survey, stream sediment and till geochemical surveys, and rock sampling, by J. L. MacLeod, June 1981. 5 pages; 4 maps (location; geological; geochemical).
21A/NW 54-A-25(02) (434348)	Uranium, South Mountain, Annapolis, Digby and Kings Counties, Nova Scotia. Shell Canada Resources Limited. Letter regarding correction of tungsten values on Map 1 in AR 21A/NW 54-A-25(01), by R. Dakers, April 1982. 1 page; 1 map (geochemical).
21A/02C 21-N-04(02) (434076)	Gold, Fifteen Mile Brook, Queens County, Nova Scotia. John D. Curphey. Report on prospecting, stripping and panning of tailings dump, by J. D. Curphey, September 1980. 8 pages; 1 map (location).
21A/02D 21-N-09(08) (434028)	Gold, Mill Village, Queens County, Nova Scotia. W. Neilly. Report on drilling, by D. R. Bell, April 1980. 34 pages; 2 maps (mine plans); drillhole logs; drillhole sections; core assays; chemical analyses.
21A/03C 54-R-32(02) (434112)	Uranium, Whitecap Lake, Yarmouth County, Nova Scotia. Can-Lake Explorations Limited (for E and B Explorations Limited). Report on geological survey, soil, rock and radon geochemical surveys and ground radiometric survey, by M. G. B. Palmer, November 1980. 52 pages; 5 maps (location; geological; geochemical; geophysical); tables, chemical analyses.
21A/04A 51-R-25(01) (434006)	Tin, East Kemptville, Yarmouth County, Nova Scotia. Shell Canada Resources Limited. Report on drilling, by B. H. Wilson, January 1980. 15 pages; 3 maps (location; drillhole location); drillhole logs; drillhole sections; core assays.
21A/04A 51-R-25(02) (434041)	Tin, East Kemptville, Yarmouth County, Nova Scotia. Shell Canada Resources Limited. Report on prospecting, boulder mapping, till fabric analysis and rock geochemistry, by B. H. Wilson, P. K. Sarkar, P. E. Sinclair, J. Richardson, S. A. Harnish and G. MacGillivray, June 1980. 17 pages; 5 maps (location; prospecting; sample location; geological; boulder counting); stratigraphic charts; chemical analyses; histograms; rose diagrams.

21A/04A 51-R-25(03) (434042)	Tin, East Kemptville, Yarmouth County, Nova Scotia. Shell Canada Resources Limited. Report on till and heavy minerals geochemical surveys, by B. H. Wilson and J. Richardson, June 1980. 8 pages; 5 maps (location; geochemical).
21A/04A 51-R-25(04) (434043)	Tin, East Kemptville, Yarmouth County, Nova Scotia. Shell Canada Resources Limited. Report on drilling, by B. H. Wilson and J. Richardson, May 1980. 38 pages; 2 maps (location; drillhole location); drillhole logs; drillhole sections; core assays.
21A/04A 51-R-25(05) (434045)	Tin, East Kemptville, Yarmouth County, Nova Scotia. Shell Canada Resources Limited. Report on drilling, by P. K. Sarkar and B. H. Wilson, June 1980. 15 pages; 2 maps (location; drillhole location); drillhole logs; drillhole sections; core assays.
21A/04A 51-R-25(06) (434046)	Tin, East Kemptville, Yarmouth County, Nova Scotia. Shell Canada Resources Limited. Report on drilling, by B. H. Wilson and G. MacGillivray, June 1980. 12 pages; 2 maps (location; drillhole location); drillhole logs; drillhole sections.
21A/04A 51-R-25(07) (434077)	Tin, East Kemptville, Yarmouth County, Nova Scotia. Shell Canada Resources Limited. Report on geology, ground magnetic and IP surveys and drilling, by R. L. Kohlsmith and B. H. Wilson, August 1980. 59 pages; 6 maps (location; drillhole location; geophysical); drillhole logs; drillhole sections; drill core chemical analyses; IP profiles.
21A/04B 51-R-25(01) (434355)	Tin, East Kemptville, Yarmouth County, Nova Scotia. Esso Minerals Canada Limited. Map showing the geochemistry of heavy minerals in till, by J. L. MacLeod, October 1981. 1 page; 1 map (geochemical).
21A/04B 51-R-25(02) (434078)	Tin, East Kemptville, Yarmouth County, Nova Scotia. Shell Canada Resources Limited. Report on geological, ground magnetic and IP surveys and drilling, by V. V. Palma, June 1980. 32 pages; 4 maps (location; drillhole location; geophysical); drillhole logs; drillhole sections; drill core assays; IP profiles.
21A/04D 51-R-25(01) (434044)	Tin, East Kemptville, Yarmouth County, Nova Scotia. Shell Canada Resources Limited. Report on geological survey, ground magnetic and ground IP surveys and drilling, by B. H. Wilson, G. MacGillivray and J. Richardson, May 1980. 40 pages; 6 maps (location; drillhole location; geological; geophysical); stratigraphic charts; drillhole logs; drillhole sections; core assays.
21A/06A 21-N-26(05) (434079)	Gold, Whiteburn, Queens County, Nova Scotia. A. Thompson. Report on the potential for open pit mining in the Whiteburn gold district, by J. E. Dawe, March 1980. 21 pages; 3 maps (location; geological).

21A/06D
54-A-26(01)
(434113)

Uranium, Twin Lakes, Annapolis County, Nova Scotia. Shell Canada Resources Limited. Report on geological survey, till, soil and rock geochemical surveys, ground radiometric survey and trenching, by D. W. T. Lewis, November 1980. 29 pages; 6 maps (location; geological; geochemical); tables, chemical analyses; trench cross sections.

21A/07C
21-L-25(06)
(434049)

Gold, Pleasant River Barrens, Lunenburg County, Nova Scotia. Claymore Management Limited. Report on property history and work proposal, by W. A. MacPherson, April 1979. 5 pages; 2 maps (location; geological).

21A/08B
21-L-40(01)
(434114)

Gold, Rose Bay, Lunenburg County, Nova Scotia. A. M. Barrett. Report on offshore and onshore geological surveys and dredge sampling, by A. M. Barrett, December 1980. 7 pages; 3 maps (location; geological).

21A/09A
51-L-41(01)
(434115)

Tin, Hennigar Mill Pond, Lunenburg County, Nova Scotia. Shell Canada Resources Limited. Report on geological survey, and till and rock geochemical surveys, by P. E. Sinclair, G. MacGillivary and B. Needham, November 1980. 14 pages, 11 maps (location; geological; surficial; geochemical); tables, chemical analyses.

21A/09A
51-L-43(01)
(434116)

Tin, East River, Lunenburg County, Nova Scotia. Shell Canada Resources Limited. Report on geological, till, rock and heavy minerals geochemical surveys, by P. E. Sinclair, G. MacGillivary and B. Needham, November 1980. 18 pages; 12 maps (location; geological; surficial; geochemical); tables, chemical analyses.

21A/05B
51-L-11(03)
(434032)

Tin, Henry Lake, Lunenburg County, Nova Scotia. N.E.X. Explorations Limited (for Shell Canda Resources Limited). Report on ground EM survey, rock geochemical survey, and drilling, by D. L. Black, May 1980. 62 pages; 3 maps (location; geochemical; geophysical); drillhole logs; drillhole sections; core assays; EM profiles; chemical analyses.

21A/09B
51-L-45(01)
(434117)

Tin, Wake Up Hill, Lunenburg County, Nova Scotia. Shell Canada Resources Limited. Report on geological, till and rock geochemical surveys, by P. E. Sinclair, G. MacGillivary and B. Needham, November 1980. 11 pages; 11 maps (location; geological; surficial; geochemical); tables, chemical analyses.

21A/09C
51-L-39(01)
(434065)

Tin, Millet Lake, Lunenburg County, Nova Scotia. Shell Canada Resources Limited. Report on geological survey and till and rock geochemical surveys, by P. E. Sinclair, July 1980. 9 pages; 11 maps (location; geological; geochemical); chemical analyses.

21A/09C 51-L-42(01) (434118)	Tin, Snyder Pond, Lunenburg County, Nova Scotia. Shell Canada Resources Limited. Report on geological, till and rock geochemical surveys, by P. E. Sinclair, G. MacGillivary and B. Needham, November 1980. 18 pages; 11 maps (location; geological; surficial; geochemical); histograms; rose diagrams; tables, chemical analyses.
21A/09C 51-L-44(01) (434119)	Tin, Besanson Lake, Lunenburg County, Nova Scotia. Shell Canada Resources Limited. Report on geological, till and rock geochemical surveys, by P. E. Sinclair, G. MacGillivary and B. Needham, November 1980. 23 pages; 10 maps (location; geological; surficial; geochemical); histograms; rose diagrams; tables, chemical analyses.
21A/09C 54-L-[illegible](03) (434018)	Uranium, New Ross, Lunenburg County, Nova Scotia. Behre Dolbear and Company Incorporated (for Canadian Fourteen Associates). Report on geological survey, stream sediment geochemical survey, and ground radiometric survey, by Behre Dolbear and Company, Incorporated, December 1979. 5 pages; 1 map (geological/geochemical/geophysical).
21A/09C 54-L-19(04) (434064)	Uranium, New Ross, Lunenburg County, Nova Scotia. Shell Canada Resources Limited. Report on geological and soil geochemical surveys, by D. W. T. Lewis, August 1980. 23 pages; 6 maps (location; geological; geochemical); chemical analyses.
21A/09C 54-L-19(05) (434089)	Uranium, New Ross, Lunenburg County, Nova Scotia. Can-Lake Explorations Limited (for E and B Explorations Limited). Report on geological survey, soil and rock geochemical surveys, soil radon, ground radiometric, ground VLF and ground magnetic surveys, and trenching and drilling, by M. G. B. Palmer, March 1980. 150 pages; 45 maps (location; drillhole location; trench location; geological; geochemical; geophysical); drillhole logs; drillhole sections; drill core chemical analyses; trench sections; rock chemical analyses; cross sections; EM profiles; magnetic profiles; gamma ray logs.
21A/09C 54-L-34(02) (434039)	Uranium, Middle River, Lunenburg County, Nova Scotia. Can-Lake Explorations Limited (for E and B Explorations Limited). Report on geological, soil and rock geochemical surveys, ground VLF and ground radiometric surveys, by M. G. B. Palmer, March 1980. 42 pages; 6 maps (location; geochemical; geophysical; geological); VLF profiles.
21A/09D 54-M-02(02) (434025)	Uranium, Hubbards River, Halifax County, Nova Scotia. Can-Lake Explorations Limited (for E and B Explorations Limited). Report on geological, soil geochemical, ground radiometric and ground VLF surveys, by M.G.B. Palmer, March 1980. 48 pages; 5 maps (location; geological; geochemical; geophysical); VLF profiles; chemical analyses.

21A/10C 54-A-23(02) (434088)	Uranium, Falkland Ridge, Annapolis County, Nova Scotia. Can-Lake Explorations Limited (for E and B Explorations Limited). Report on geological survey, soil and rock geochemical surveys, ground radiometric, ground VLF and ground magnetic surveys, by M. G. B. Palmer, May 1980. 52 pages; 5 maps (location; geological; geochemical; geophysical); VLF profiles; magnetic profiles; tables, chemical analyses.
21A/10D 54-K-28(02) (434120)	Uranium, East Dalhousie, Kings County, Nova Scotia. Can-Lake Explorations Limited (for E and B Explorations Limited). Report on geological, soil geochemical and ground radiometric surveys, by M. G. B. Palmer, November 1980. 37 pages; 4 maps (location; geological; geochemical; geophysical); tables, chemical analyses.
21A/10D 54-L-31(02) (434021)	Uranium, Sherbrooke Lake, Lunenburg County, Nova Scotia. Esso Resources Canada Limited. Report on geological and ground radiometric surveys and drilling, by Y. S. Lowe, February 1980. 9 pages; 4 maps (location; geological; geophysical; drillhole location); drillhole logs; drillhole sections; gamma ray logs; assays.
21A/10D 54-L-31(03) (434062)	Uranium, Sherbrooke Lake, Lunenburg County, Nova Scotia. Eldorado Nuclear Limited. Report on geological, soil geochemical and ground radiometric surveys, by H. Laanela, July 1980. 70 pages; 6 maps (location; geological; sample location; geochemical; geophysical); histograms.
21A/16B 54-L-37(03) (434121)	Uranium, Harris Lake, Lunenburg County, Nova Scotia. Norcen Energy Resources Limited, Vancouver Petrographics Limited and Esso Minerals Canada Limited (for Norcen Energy Resources Limited, Campbell Resources Incorporated, E and B Explorations Limited and Ontario-Hydro). Report on geological survey, soil, till and stream sediment geochemical surveys, ground magnetic survey and a re-evaluation of drilling results, by T. Bojczyszyn, T. Turner, J. O'Sullivan and J. Newlands, December 1980. 78 pages; 13 maps (location; geological; geochemical; geophysical); tables, chemical analyses.
21A/16C 54-K-26(02) (434038)	Uranium, Black River Lake, Kings County, Nova Scotia. M. E. X. Explorations Limited (for A. Hudgins). Report on geological, rock geochemical and ground radiometric survey, by L. D. Rankin, February 1980. 13 pages; 3 maps (location; geological); tables, chemical analyses.
21A/16C 54-K-30(01) (434060)	Uranium, Little River Lake, Kings County, Nova Scotia. M. E. X. Explorations Limited (for Shell Canada Resources Limited). Report on geological survey, stream sediment and rock geochemical surveys and ground radiometric survey, by L. D. Rankin, February 1980. 15 pages; 9 maps (location; geological; geochemical); tables, chemical analyses.

21H/01D 07-I-05(02) (434003)	Base Metals, Cheverie, Hants County, Nova Scotia. Gulf Minerals Canada Limited. Report on soil geochemical survey, by R. T. Boyd, December 1979. 105 pages; 22 maps (location; geochemical); stratigraphic charts; chemical analyses.
21H/01D 07-I-51(09) (434004)	Base Metals, Walton, Hants County, Nova Scotia. Gulf Minerals Canada Limited. Report on soil geochemical survey, by R. T. Boyd, December 1979. 192 pages; 26 maps (location; geochemical); stratigraphic charts; chemical analyses.
21H/02A 54-K-31(01) (434091)	Uranium, Prospect, Kings County, Nova Scotia. Shell Canada Resources Limited. Report on prospecting, geological and ground radiometric surveys, by R. Van Deudekom and G. B. Dickie, March 1982. 9 pages; 1 map (geological); stratigraphic charts.
21H/09A 54-E-42(01) (434024)	Uranium, Springhill South, Cumberland County, Nova Scotia. Brinex Limited. Report on geological survey, stream sediment and rock geochemical surveys, by F. Gentile, April 1980. 23 pages; 3 maps (physiographic; geological; geochemical); chemical analyses.

APPENDIX XX

OPEN FILE REPORTS FOR 1982

OPEN FILE REPORTS FOR 1982

OFR 480 Tin and tungsten data from tills sampled along the Eastern Shore region, Nova Scotia, by R. R. Stea, 1982. 8 pages; chemical analyses.

OFR 481 Colour compilation maps for reconnaissance airborne gamma ray spectrometric surveys covering Nova Scotia, NTS - 11D, 11E, 11F, 11G, 11H, 20O, 21A, 21B and 21H, by Nova Scotia Department of Mines and Energy and Geological Survey of Canada, 1982. 7 pages; 5 maps (geophysical); GSC Open File 846.

OFR 482 Colour compilation maps for lake sediment geochemical surveys covering the Meguma terrane and adjacent areas, NTS - 11D, 20O, 20P, 21A, parts of 11E, 11F, 21B and 21H, by Nova Scotia Department of Mines and Energy and Geolgoical Survey of Canada, 1982. 9 pages; 17 maps (geochemical); GSC Open File 847.

OFR 483 Submission to Legislative Committee on Mines and Minerals for 1979, by Nova Scotia Department of Mines and Energy, 1980. 64 pages; 6 maps (exploration activity).

OFR 484 Proposal for drilling program on offshore coal development in the Sydney Basin, Nova Scotia, by R. B. German and H. A. J. Hatich, 1976. 44 pages; 1 map (drillhole location).

OFR 485 Mineralogy of Nova Scotia, by H. How, 1869. 217 pages.

OFR 486 Peatland inventory program, by A. R. Anderson and W. Broughm, 1982. 58 pages; 8 maps (peat deposit location; peat topography); chemical analyses.

OFR 487 Mineral possibilities of Indian Reserve Bear River No. 6A, Annapolis County, Nova Scotia, by J. D. Wright, 1972. 5 pages.

OFR 488 Mineral possibilities of Indian Reserve Bear River No. 6, Digby County, Nova Scotia, by J. D. Wright, 1972. 9 pages, drillhole logs.

OFR 489 Evaluation of mineral potential of Whycocomagh No. 2 Indian Reservation, Inverness County, Nova Scotia, by J. D. Wright, 1971. 53 pages.

OFR 490 Notes on mineral possibilities of Malagawatch No. 4 Indian Reservation, Inverness County, Nova Scotia, by J. D. Wright, 1971. 17 pages.

OFR 491 Evaluation of mineral potential of Middle River No. 1 Indian Reservation, Victoria County, Nova Scotia, by J. D. Wright, 1971. 6 pages.

OFR 492 Mineral evaluation of Eskasoni Indian Reservations Nos. 3 and 3A, Cape Breton County, Nova Scotia, by J. D. Wright, 1971. 36 pages.

OFR 493 Economic evaluation of mineral potential of Chapel Island Indian Reservation No. 5, Richmond County, Nova Scotia, by J. D. Wright, 1971. 13 pages.

OFR 494 Mineral potential of Margaree No. 25 Indian Reservation, Inverness County, Nova Scotia, by J. D. Wright, 1971. 13 pages.

OFR 495 Mineral potential of Port Hood No. 26 Indian Reservation, Inverness County, Nova Scotia, by J. D. Wright, 1971. 21 pages.

OFR 496 Mineral evaluation of Sydney No. 28A Indian Reservation, Cape Breton County, Nova Scotia, by J. D. Wright, 1971. 8 pages.

OFR 497 Mineral evaluation of Sydney No. 28B Indian Reservation, Cape Breton County, Nova Scotia, by J. D. Wright, 1971. 19 pages.

OFR 498 Mineral potential of Caribou Marsh Indian Reservation No. 29, Cape Breton County, Nova Scotia, by J. D. Wright, 1971. 8 pages.

OFR 499 Summary of the mineral potential of Indian Reservations of Cape Breton Island, Nova Scotia, by J. D. Wright, 1971. 3 pages.

OFR 500 Mineral possibilities of Indian Reservation Beaver Lake No. 17, Halifax County, Nova Scoita, by J. D. Wright, 1972. 5 pages.

OFR 501 Mineral possibilities of Indian Reservations Boat Harbour West No. 37, Fishers Grant No. 24 and Fishers Grant No. 24G, Pictou County, Nova Scotia, by J. D. Wright, 1972. 6 pages.

OFR 502 Economic mineral potential of Indian Reservation Cambridge No. 32, Kings County, Nova Scotia, by J. D. Wright, 1972. 4 pages.

OFR 503 Mineral possibilities of Indian Reservation Cole Harbour No. 30, Halifax County, Nova Scotia, by J. D. Wright, 1972. 8 pages.

OFR 504 Mineral evaluation of Indian Reservation Franklin Manor No. 22, Cumberland County, Nova Scotia, by J. D. Wright, 1972. 8 pages; drillhole log.

OFR 505 Mineral possibilities of Gold River Indian Reservation No. 21, Lunenburg County, Nova Scotia, by J. D. Wright, 1972. 4 pages; 2 maps (property ownership).

OFR 506 Investigation of Department of Highways proposed right-of-way across the Gold River Indian Reservation No. 21, Lunenburg County, Nova Scotia, by J. H. Fowler, 1972. 2 pages.

OFR 507 Mineral possibilities of Horton Indian Reservation No. 35, Kings County, Nova Scotia, by J. D. Wright, 1972. 5 pages.

OFR 508 Mineral potential of Indian Reservation Medway River No. 11, Queens County, Nova Scotia, by J. D. Wright, 1972. 5 pages.

OFR 509 Mineral evaluation of Merigomish Harbour Indian Reservation No. 31, Pictou County, Nova Scotia, by J. D. Wright, 1972. 4 pages.

OFR 510 Mineral potential of Indian Reservations Mill Brook No. 27, Truro No. 27A, Truro No. 27B and Truro No. 27C, Colchester County, Nova Scotia, by J. D. Wright, 1972. 9 pages.

OFR 511 Mineral possibilities of Indian Reservation New Ross No. 20, Lunenburg County, Nova Scotia, by J. D. Wright, 1972. 7 pages.

OFR 512 Mineral possibilities of Indian Reservation Pennall No. 19, Lunenburg County, Nova Scotia, by J. D. Wright, 1972. 6 pages.

OFR 513 Geological report on Indian Reservation No. 23 Pomquet and Afton, Antigonish County, Nova Scotia, by J. D. Wright, 1972. 9 pages; drillhole logs.

OFR 514 Mineral possibilities of Indian Reservation Ponhook Lake No. 10, Queens County, Nova Scotia, by J. D. Wright, 1972. 5 pages.

OFR 515 Mineral possibilities of St. Croix Indian Reservation No. 34, Hants County, Nova Scotia, by J. D. Wright, 1972. 4 pages.

OFR 516 Mineral possibilities of Indian Reservation Sheet Harbour No. 36, Halifax County, Nova Scotia, by J. D. Wright, 1972. 9 pages.

OFR 517 Economic appraisal of Indian Reservation Shubenacadie No. 14, Hants County, Nova Scotia, by J. D. Wright, 1972. 12 pages.

OFR 518 Mineral evaluation of Indian Reservation Shubenacadie No. 13, Halifax County, Nova Scotia, by J. D. Wright, 1972. 5 pages.

OFR 519 Mineral possibilities of Indian Reservation Wildcat No. 12, Queens County, Nova Scotia, by J. D. Wright, 1972. 6 pages.

OFR 520 Mineral evaluation of Indian Reservation No. 33, Yarmouth County, Nova Scotia, by J. D. Wright, 1972. 5 pages.

OFR 521 Compilation of uranium exploration activities in Nova Scotia up to the end of 1979, by H. A. Lyttle and J. Gillespie-Wood, 1982. 21 pages; 1 map (exploration licenses location); exploration activity tables.

OFR 522 Investigation of geothermal energy resources of Nova Scotia and Prince Edward Island, by J. A. Leslie, 1981. 124 pages; 1 map (drillhole location); geothermal logs; chemical analyses.

OFR 523 Chemical analyses of Paleozoic volcanic rocks of Nova Scotia, by J. Dostal, J. D. Keppie and C. Duprey, 1982.

OFR 524 Evaluation of the Spencer seam for near surface coal, Cape Breton County. Nova Scotia, by K. S. Gillis, 1982. 24 pages; 6 maps (geological; drillhole location; structure contours; isopachs; isocons; isochores); cumulative curves; chemical analyses; drillhole sections; density profiles.

OFR 525 Evaluation of the Mullins seam for near surface coal, Cape Breton County, Nova Scotia, by K. S. Gillis, 1981. 16 pages; 8 maps (geological; drillhole locations; isopachs; isocons; isochores; structure contours); chemical analyses; drillhole sections; density profiles.

OFR 526 Submission to the Nova Scotia Uranium Inquiry on behalf of Kidd Creek Mines Limited, by G. W. Mannard, D. Pollock, R. Turton, D. Miller, R. D. John and D. Chambers, 1982. 102 pages; 3 maps (location); mine cross sections; flow charts; histograms.

OFR 527 Metallogenic Studies of southeastern Cape Breton Island Nova Scotia - Preliminary Report, by A. S. Macdonald, 1982. 204 pages; 10 maps (geological); stratigraphic charts; stereonets; drillhole sections; photographs; photomicrographs; chemical analyses; variation diagrams; ternary diagrams; structural cross sections.

OFR 528 The marine mining potential of Nova Scotia for sand and gravel, by C. Miller, 1981. 34 pages; 6 maps (surfical; mineral location; location); cross sections; stratigraphic charts.

OFR 529 The Yava Lead Deposit, Salmon River, Cape Breton, exploration (1962-1981) and mining activities (1979-1981), by O. J. H. Bonham, M. Doucet, F. Johnson and Nova Scotia Department of Mines and Energy, 1982. 55 pages; 11 maps (location; drillhole location; geological; ore reserves; lead grade contours; mine plans; land ownership); photographs; stratigraphic charts and cross sections; drillhole sections; exploration and mining activities table; tables, ore reserves; tables, production; flow chart, milling.

OFR 530 Submission to the Nova Scotia Uranium Inquiry, by Nova Scotia Department of the Environment, 1982. 43 pages.

OFR 531 Feasibility of continued operations at Yava Mines Limited, by Nova Scotia Department of Mines and Energy, 1981. 21 pages.

OFR 532 The Yava Mines Limited Concentrator, by M. Doucet, 1981. 23 pages; flow chart, milling.

OFR 533 Report on Yava Mine, by F. A. Johnson, 1981. 28 pages.

OFR 534 Structural analysis of Nova Scotia structures, by J. P. Richert, 1973. 7 pages; 1 map (geological); stereograms; structural cross sections.

APPENDIX III

NOVA SCOTIA DEPARTMENT OF MINES AND ENERGY

PUBLICATIONS AND MAPS FOR SALE

Orders for publications and maps may be sent to the Library, Nova Scotia Department of Mines and Energy, P. O. Box 1087, Halifax, Nova Scotia B3J 2X1.

Cheques or money orders must be in Canadian funds and should be payable to the Minister of Finance.

NOVA SCOTIA DEPARTMENT OF MINES AND ENERGY

PUBLICATIONS AND MAPS FOR SALE

PAPERS

Paper 76-1	Structural Model for the Saddle Reef and Associated Veins in the Meguma Group, Nova Scotia, by J. D. Keppie, 34 pages & 2 maps.	$3.00
Paper 76-2	Geological Data Collection in the Nova Scotia Department of Mines, by J. D. Keppie and A. K. Chatterjee, 15 pages.	$0.50
Paper 76-3	Interpretation of P.P.I. Radar Imagery of Nova Scotia, by J. D. Keppie, 31 pages & map.	$1.25
Paper 76-4	Geology, Geochemistry and Mineral Occurrences of the Northeast Margaree River Drainage Basin in parts of Inverness and Victoria Counties, Cape Breton, Nova Scotia, by B. E. MacNabb, J. H. Fowler and T. G. N. Covert, 30 pages & 12 maps.	$15.00
Paper 76-5	Guide to the Invertebrate Fauna of the Windsor Group in Atlantic Canada, by R. G. Moore and R. J. Ryan, 57 pages.	$2.25
Paper 77-1	Tectonics of Southern Nova Scotia, by J. D. Keppie, 34 pages (Reprinted 1980).	$3.00
Paper 77-3	Plate Tectonic Interpretation of Paleozoic World Maps (with Emphasis on Circum-Atlantic Orogens and Southern Nova Scotia), by J. D. Keppie, 45 pages. (Reprinted 1982) (Microfiche $1.50)	$4.00
Paper 77-6	Sand and Gravel Resources of Pictou County, by J. H. Fowler and G. B. Dickie, 42 pages & map.	$4.00
Paper 77-7	Tungsten Mineralization in the Carbonate Rocks of the George River Group, Cape Breton Island, Nova Scotia, by A. K. Chatterjee, 26 pages.	$3.50
Paper 78-1	Geology of the Ecum Secum Area, Halifax and Guysborough Counties, Nova Scotia, by D. McBride, 12 pages.	$1.00
Paper 78-2	Age of Igneous Rocks along the Lennox Passage - St. Peter's Lineament, Southern Cape Breton Island, by J. D. Keppie and P. K. Smith, 10 pages.	$1.00
Paper 78-3	Geology of the Giant Lake Area, Southeastern Cape Breton Island, Nova Scotia, by P. K. Smith, 30 pages & map.	$2.00
Paper 78-4	Some Middle Devonian to Lower Carboniferous Rocks of Cape George, Nova Scotia, by J. D. Keppie, P. S. Giles, and R. C. Boehner, 37 pages.	$2.00
Paper 78-5	Petrology of the Early Silurian Dunn Point and McGillivray Brook Formations, Arisaig, Nova Scotia, by J. D. Keppie, J. Dostal and M. Zentilli, 20 pages.	$1.00

Paper 79-1	Petrology of the Late Precambrian Fourchu Group in the Louisbourg Area, Cape Breton Island, by J. D. Keppie, J. Dostal and J. B. Murphy, 18 pages.	$1.50
Paper 79-2	Opencast Coal Reserves at Springhill, by B. Ward, 40 pages & 4 maps.	$4.50
Paper 79-3	Geology of the Meat Cove Zinc Deposit, Cape Breton Island, by A. K. Chatterjee, 27 pages.	$2.00
Paper 79-4	Minor and Trace Element Variations in Wisconsinan Tills Eastern Shore Region, Nova Scotia, by R. R. Stea and J. H. Fowler, 30 pages & 3 maps.	$10.00
Paper 79-5	Pleistocene Stratigraphy of the Miller Creek Section, Hants County, Nova Scotia, by R. Stea and D. Hemsworth, 16 pages.	$3.00
Paper 79-6	Effects of Subsidence and Depositional Environment on the Formation of Lithotypes in a Hypautochthonous Coal of the Pictou Coalfield, by J. H. Calder, 23 pages.	$3.00
Paper 79-7	Carbonate Banks of the Gays River Formation in Central Nova Scotia, by P. S. Giles, R. C. Boehner and R. J. Ryan, 57 pages & map.	$4.00
Paper 80-1	Geology of the Cape North Area, Northern Cape Breton Island, Nova Scotia, by A. S. Macdonald and P. K. Smith, 60 pages & 2 maps. (Microfiche $2.00)	$5.00
Paper 81-1	The Fisset Brook Formation at Lowland Cove, Inverness County, Nova Scotia, by P. K. Smith and A. S. Macdonald, 18 pages. (Microfiche $1.00)	$2.00
Paper 81-2	Major Transgressive - Regressive Cycles in Middle to Late Visean Rocks of Nova Scotia, by P. S. Giles, 27 pages. (Microfiche $1.50)	$2.00
Paper 81-3	The Windsor Group of the Mahone Bay Area, Nova Scotia, by P. S. Giles, 51 pages, figure in back pocket. (Microfiche $1.50)	$4.00
Paper 81-4	Principles of Tectonic Mapping Based upon Plate Tectonic Theory, by J. D. Keppie, 11 pages. (Microfiche $1.00)	$1.50
Paper 82-1	Geology and Geochemistry of Selected Granitoid Plutons of Cape Breton Island, by S. M. Barr, G. A. O'Reilly and A. M. O'Beirne, 176 pages, 44 figs., 13 tables. (Microfiche $2.00)	$8.00
Paper 82-2	Metasomatic-Hydrothermal Mineral Deposits of the New Ross-Mahone Bay Area, Nova Scotia, by G. A. O'Reilly, E. J. Farley and M. H. Charest, 96 pages. (Microfiche $1.50)	$5.00

REPORTS

Report 75-1	Report of Activities of the Mineral Resources and Geological Services Division, 1974, by Nova Scotia Department of Mines, 75 pages.	$1.00
Report 76-1	Drilling Logs of Government Core Drills, 1974, by I. MacDougall and D. W. Grimm, 73 pages.	$1.00
Report 76-2	Mineral Resources Division, Report of Activities, 1975, 145 pages.	$3.00
Report 76-3	Drilling Logs of Government Core Drills, 1975, by I. MacDougall and D. W. Grimm, 47 pages.	$1.00
Report 77-1	Mineral Resources Division, Report of Activities, 1976, 207 pages.	$10.00
Report 77-2	Superseded by Report 81-4.	
Report 77-3	Drilling Logs of Government Core Drills, 1976, by I. MacDougall and D. W. Grimm, 33 pages.	$1.00
Report 78-1	Mineral Resources Division, Report of Activities, 1977, 104 pages.	$4.00
Report 78-2	Drilling Logs of Government Core Drills, 1977, by I. MacDougall and D. E. Polley, 72 pages.	$2.00
Report 78-3	Superseded by Report 81-6	
Report 78-4	Compilation of Isotopic Age Data of Nova Scotia, by J. D. Keppie and P. K. Smith, 54 pages & 7 maps.	$7.00
Report 79-1	Mineral Resources Division, Report of Activities, 1978, 177 pages.	$6.00
Report 79-2	Drilling Logs of Government Core Drills, 1978, by I. MacDougall and D. E. Polley, 54 pages.	$2.00
Report 80-1	Mineral Resources Division, Report of Activities, 1979, 248 pages.	$7.00
Report 80-2	Index to Drilling Logs of Government Core Drills, 1972-78, by N. A. Lyttle and J. Gillespie-Wood, 47 pages.	$3.00
Report 80-3	Drilling Logs of Government Core Drills, 1979, by I. MacDougall and D. E. Polley, 68 pages. (Microfiche $1.50)	$3.50
Report 81-1	Mineral Resources Division, Report of Activities, 1980, 199 pages. (Microfiche $2.00)	$8.00
Report 81-2	Compilation of Igneous Chemical Analyses from Nova Scotia, up to 1978, compiled by J. D. Keppie, P. K. Smith and M. A. K. Grice, 114 pages. (Microfiche $2.00)	$4.00
Report 81-3	Drilling Logs of Government Core Drills, 1980, by I. MacDougall and D. E. Polley, 52 pages. (Microfiche $1.00)	$3.50
Report 81-4	Index to Assessment Reports 1864-1980, by N. A. Lyttle and J. Gillespie-Wood, 109 pages. (Microfiche $3.00)	$10.00
Report 81-5	Keyword Index to Assessment Reports, 1864-1980, by N. A. Lyttle and J. Gillespie-Wood. (Microfiche only $5.00)	

Report 81-6	Index to Publications, Open File Reports and Theses, 1862-1980, by N. A. Lyttle and J. Gillespie-Wood, 222 pages. (Microfiche $3.00)	$10.00
Report 81-7	Index to Drillhole and Well Data, 1862-1980, by N. A. Lyttle and J. Gillespie-Wood, 127 pages. (Microfiche $3.00)	$10.00
Report 82-1	Mineral Resources Division, Report of Activities, 1981, 139 pages. (Microfiche $2.00)	$7.00
Report 82-2	Index to Assessment Reports, 1981 (with Keyword Index), by N. A. Lyttle and J. Gillespie-Wood, 11 pages. (Microfiche $2.00)	$3.00
Report 82-3	Keyword Index to Publications in NSDME Report 81-6, by N. A. Lyttle and J. Gillespie-Wood. (Microfiche only $2.00)	
Report 82-4	Keyword Index to Open File Reports in NSDME Report 81-6, by N. A. Lyttle and J. Gillespie-Wood. (Microfiche only $1.00)	
Report 82-5	Keyword Index to GSC Documents on Nova Scotia to 1980. (Microfiche only $2.00)	
Report 82-6	Drilling Logs of Government Core Drills, 1981, compiled by Ian MacDougall and D. E. Polley, 1982, 60 pages. (Microfiche $1.50)	$3.50
Report 82-7	Uranium in Nova Scotia: A Background Summary for the Uranium Inquiry, Nova Scotia, 122 pages & 2 maps. (Microfiche $2.00)	$10.00
Report 83-2	Index to Assessment Reports, 1982 (with Keyword Index), by N. A. Lyttle and J. Gillespie-Wood, 32 pages. (Microfiche $2.00)	$3.00

MEMOIRS

Memoir 4	The Older Paleozoic of Pictou County, Nova Scotia, by R. H. Maehl, 1961, 109 pages & appendix & map.	$3.00
Memoir 5	Pleistocene Geology of the Annapolis Valley, Nova Scotia, by C. F. Hickox, 1962, 36 pages & map.	$2.00
Memoir 7	The Geology of the George River Series, Cape Breton, by G. C. Milligan, 1970, 111 pages & 7 maps.	$4.50

BULLETINS

Bulletin 1	Port Hawkesbury Project - Geology, Geochemistry and Groundwater Investigations of Southwest Inverness and Richmond Counties, Nova Scotia, by F. S. Shea and J. D. Wallace, 1962, 73 pages & 5 maps.	$2.00
Bulletin 2 (Part 1)	Limestones and Dolomites of Nova Scotia, Part I-Cape Breton Island, by F. S. Shea and D. A. Murray, 1969, 300 pages & map.	$4.00

Bulletin 2 (Part 2)	Limestones and Dolomites of Nova Scotia, Part II-Antigonish, Guysborough, Pictou, and Cumberland Counties, by D. A. Murray, 1975, 155 pages.	$6.50
Bulletin 3	Assessment of Peat Moss Occurrences in Guysborough, Antigonish, Pictou, Colchester and Cumberland Counties, Nova Scotia, by D. R. Sutherland and F. S. Shea, 1976, 301 pages.	$7.00
Bulletin 4	Barite, Celestite and Fluorite in Nova Scotia, by G. W. Felderhof, 1978, 463 pages, 200 figures, 12 tables.	$13.00

INFORMATION SERIES

No. 1	Geology, Minerals and Mining in Nova Scotia, by J. M. Richardson and D. J. Gregory, 1976, 22 pages.	Free
No. 2	A History of Coal Mining in Nova Scotia, compiled by D. J. Gregory, 1978, 41 pages.	Free
No. 3	Program and Summaries, Fourth Annual Open House and Review of Activities of the Mineral Resources Division, by Nova Scotia Department of Mines and Energy, 1980, 106 pages.	$1.00
No. 4	Program and Summaries, Fifth Annual Open House and Review of Activities, by Nova Scotia Department of Mines and Energy, 1981, 51 pages. (Microfiche $1.00)	$1.00
No. 5	Program and Summaries, Sixth Annual Open House and Review of Activities, by Nova Scotia Department of Mines and Energy, 1982, 69 pages. (Microfiche $1.00)	$1.00

REPRINT SERIES

No. 1	Paleozoic Volcanic Rocks of Nova Scotia, by J. D. Keppie and J. Dostal, 1980, 8 pages. Reprinted from - Proceedings: "The Caledonides in the U.S.A." I.G.C.P. Project 27: Caledonide Orogen.	$1.00
No. 2	Granitoid and Other Plutonic Rocks of Nova Scotia, by D. B. Clarke, S. M. Barr and H. V. Donohoe, 1980, 10 pages. Reprinted from - Proceedings: "The Caledonides in the U.S.A." I.G.C.P. Project 27: Caledonide Orogen.	$1.00
Reprint 81-1	Determination of Gold in Natural Waters at the Parts-per-Trillion (pg cm^{-3}) level, by Robert R. Brooks, Amulaya K. Chatterjee and Douglas E. Ryan, 7 pages. Reprinted from Chemical Geology, 33, 1981. (Microfiche $1.00)	$1.50

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